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IN-FLIGHT INVESTIGATION OF LARGE AIRPLANE FLYING QUALITIES FOR APPROACH AND LANDING

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A study of the handling qualities of large airplanes in the approach and landing flight phase was performed. An in-flight simulation experiment utilizing the USAF-AFWAL/Calspan Total In-flight Simulator was carried out to gather data for the analysis effort. A one-million pound statically unstable airplane model was used as a baseline about which variations were made. The primary variables were relative pilot position with respect to center of rotation, command path time delays and

phase shifts, augmentation schemes and levels of augmentation. Both longitudinal and lateral-directional characteristics were investigated. The experiment design, conduct of the experiment, and analysis of the data are described. Results are presented in the form of pilot ratings, pilot comments and various analysis techniques. The results indicate that the approach and landing task with very large airplanes is a fairly low bandwidth task. Low equivalent short-period frequencies and relatively long time delays can be tolerated. As the pilot position is moved aft towards and then behind the center of rotation, pilot ratings are degraded. A multiloop analysis of pitch attitude and altitude control gave insight into this pilot position phenomenon. Altitude loop bandwidth correlated well with pilot ratings. The control problem experienced by the pilots, when flying the airplane while seated behind the center of rotation, tended to occur at low altitude when they were using visual cues of rate of sink and altitude. These aft pilot position configurations, similar to the space shuttle orbiter, also lack the initial normal acceleration cue from pitch acceleration that the other conventional large airplane configurations possess. A direct lift controller improved final flight path control of the shuttle-like configurations. Lateral acceleration levels that are achievable in very large airplanes degrade pilot ratings as predicted by the lateral acceleration parameter: $n_{y_{p_{max}}}/\dot{p}_{max}$.

FOREWORD

This report was prepared for the United States Air Force by the Calspan Advanced Technology Center, Buffalo, New York, in partial fulfillment of Contract No. F33615-79-C-3618. The report describes the results of a flight research program performed under that contract conducted in the Total In-Flight Simulator (TIFS).

The flying qualities experiment reported herein was performed by the Flight Research Department of Calspan under joint sponsorship of the Wright Aeronautical Laboratories (Flight Dynamics Laboratory), Wright-Patterson Air Force Base, Ohio, and the National Aeronautics and Space Administration, Dryden Flight Research Center, Edwards, California. Program monitors were Mr. Robert Woodcock from the Air Force Flight Dynamics Laboratory and Donald Berry from NASA Dryden. Mr. Jack Barry was the Program Manager for the overall TIFS programs from the Air Force Flight Dynamics Laboratory.

This report represents the combined efforts of many members of the Flight Research Department. Mr. Charles Chalk was the Principal Investigator and Norman C. Weingarten was the Project Engineer. Dr. Philip A. Reynolds was the Program Manager for the overall TIFS contract. The contributions of the following individuals are also gratefully acknowledged:

Messrs. Nello Infanti, Michael Parrag, and Charles Berthe — TIFS Safety Pilots.
Messrs. Robert Harper, Jr. and Rogers E. Smith — Evaluation Pilots.
Mr. Thomas Gavin — Electronic Systems Engineer.
Mr. Thomas Franclemont — Electronics Maintenance.
Messrs. Raymond Miller and William Frey — Aircraft Maintenance.
Mrs. Janet Cornell and Mrs. Chris Turpin — Report Preparation.

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ADI	=	Attitude director indicator
b	=	wing span, ft
$\bar{c}$	=	mean aerodynamic chord, ft
C_D, C_{D_o}	=	drag coefficient = $D/\bar{q}S$, drag coefficient at zero α
C_{D_i}	=	$\partial C_D/\partial i$, $i = \alpha$, δ_e, deg^{-1}
$c.g.$	=	center of gravity
C_L	=	lift coefficient = $L/\bar{q}S$
C_{L_o}	=	lift coefficient at zero angle of attack
C_{L_i}	=	$\partial C_L/\partial i$, $i = \alpha$, δ_e, δ_{DLC}, deg^{-1}
C_{L_j}	=	$\left(\frac{2V}{\bar{c}}\right) \partial C_L/\partial j$, $j = \dot{\alpha}$, q, deg^{-1}
C_ℓ	=	rolling moment coefficient = $L/\bar{q}Sb$
C_{ℓ_i}	=	$\partial C_\ell/\partial i$, $i = \beta$, δ_a, δ_r, deg^{-1}
C_{ℓ_j}	=	$\left(\frac{2V}{b}\right) \partial C_\ell/\partial i$, $j = p$, r, deg^{-1}
C_m	=	pitching moment coefficient = $M/\bar{q}S\bar{c}$
C_{m_o}	=	pitching moment coefficient at zero angle of attack
C_{m_i}	=	$\partial C_m/\partial i$, $i = \alpha$, δ_e, deg^{-1}
C_{m_j}	=	$\left(\frac{2V}{\bar{c}}\right) \partial C_m/\partial j$, $j = \dot{\alpha}$, q, deg^{-1}
C_n	=	yawing moment coefficient = $N/\bar{q}Sb$
C_{n_i}	=	$\partial C_n/\partial i$, $i = \beta$, δ_a, δ_r, deg^{-1}
C_{n_j}	=	$\left(\frac{2V}{b}\right) \partial C_n/\partial j$, $j = p$, r, deg^{-1}
C_y	=	side force coefficient = $Y/\bar{q}S$
C_{y_i}	=	$\partial C_y/\partial i$, $i = \beta$, δ_a, δ_r, deg^{-1}
C_{y_j}	=	$\left(\frac{2V}{b}\right) \partial C_y \partial j$, $j = p$, r, deg^{-1}
D	=	drag, lb
DLC	=	direct lift control
dB	=	decibel units for Bode amplitude = 20 $\log_{10}$(amplitude)
F_{AW}	=	aileron wheel force, lb
F_{ES}	=	elevator wheel force, positive aft, lb
F_{RP}	=	rudder pedal force, lb , positive, right pedal forward

g	=	gravitational constant = 32.17 ft/sec^2
h	=	altitude of airplane c.g., ft
h_c	=	commanded change in airplane altitude at pilot station, ft
h_p	=	altitude of airplane at pilot station, ft
h_{WH}	=	altitude of airplane at model wheels, ft
h_ϵ	=	$(h_c - h_p)$, error between the commanded altitude and altitude at the pilot station, ft
h_T	=	altitude of airplane at TIFS wheels, ft
HSI	=	Horizontal Situation Indicator
I_{xx}, I_{yy}, I_{zz}	=	moments of inertia about X, Y, Z body axes, slug-ft^2
I_{xz}	=	product of inertia about X, Z body axes, slug-ft^2
IFR	=	Instrument Flight Rules
K_{p_h}	=	steady state pilot gain in altitude loop closure, rad/ft
K_{p_θ}	=	steady state pilot gain in attitude loop closure, lb/rad-sec
K_q	=	loop gain in pitch rate augmentation system, deg/deg/sec
K_α	=	angle of attack feedback gain, deg/deg
L	=	lift, lb
L, M, N	=	moments about X, Y, Z body axes, ft-lb
m	=	mass of airplane, slugs
n_y, n_z	=	lateral, normal acceleration, g's (n_y + right, n_z + down)
n_j^i	=	transfer function numerators
p, q, r	=	roll, pitch, yaw rates, deg/sec
$PIOR$	=	pilot-induced oscillation rating
PR	=	pilot rating
ϕ_{PC}	=	phase angle of pilot compensation, $\tan^{-1}(\tau_L \omega_{BW})$, deg
$\bar{q}$	=	dynamic pressure = $\frac{1}{2}\rho V^2$, lb/ft^2
s	=	Laplace operator, sec^{-1}
S	=	reference wing area, ft2
T	=	total thrust, lb
T_D	=	equivalent time delay from equivalent systems analysis, sec

LIST OF SYMBOLS (Cont'd)

T_q	=	integration time constant in pitch rate augmentation system, sec
T_1	=	notation for level of delay in configuration description
t_1	=	effective time delay from maximum slope intercept method, sec
TIFS	=	Total In-flight Simulator
Δt	=	rise time from time history criteria analysis, sec
V	=	true airspeed, ft/sec
V_I	=	inertial speed, ft/sec
V_x, V_y, V_z	=	velocity components along X, Y, and Z body axes, ft/sec
W	=	airplane weight, lb
X,Y,Z	=	body axes, X-Z plane is in plane of symmetry with X directed forward parallel to the fuselage reference line, Z directed downward, and Y directed out the right wing
X_{MP}	=	distance along X-body axis between c.g. and pilot station, ft
X_{PCR}	=	distance along X-body axis between instantaneous center of pitch rotation and pilot station, ft
Y_{c_θ}	=	aircraft θ/F_{ES} transfer function
Y_{P_h}	=	pilot describing function in altitude loop closure
Y_{P_θ}	=	pilot describing function in attitude loop closure
Z_{SP}	=	distance between pilot station and X-stability axis, negative for pilot above stability axis, ft
α	=	angle of attack, deg
α_g	=	turbulence component of angle of attack, deg
α_T	=	total angle of attack (inertial + wind and turbulence), deg
α_I	=	inertial angle of attack (with respect to inertial velocity), deg
β	=	sideslip, deg
β_g	=	turbulence component of sideslip, deg
β_T	=	total sideslip (inertial + wind and turbulence), deg
β_I	=	inertial sideslip (with respect to inertial velocity), deg
γ	=	flight path angle, deg
Δn_z	=	incremental normal acceleration, g's

LIST OF SYMBOLS (Cont'd)

δ_a = aileron surface deflection, included angle positive left T.E. down, deg

δ_{AW} = aileron wheel deflection, positive clockwise, deg

δ_{AWC} = aileron command positive left T.E. down, deg

δ_e = elevator surface deflection, positive T.E. down, deg

δ_{EC} = elevator column deflection, positive aft, inch

δ_r = rudder surface deflection, positive T.E. left, deg

δ_{RP} = rudder pedal deflection, positive right pedal forward, inch

δ_{RPC} = rudder command, positive T.E. left, deg

δ_{th} = throttle lever position, deg

$[\Delta A/\Delta \measuredangle]_\theta$ = slope of Bode amplitude with phase for the airplane plus pilot delay at reference frequency for pitch attitude loop, dB/deg

$\Delta \measuredangle_\theta$ = differential phase angle of the airplane plus pilot delay at reference frequency for pitch attitude loop, deg

ζ = damping ratio

ζ_d = damping ratio of Dutch roll mode

ζ_{ph} = damping ratio of phugoid mode

ζ_{sp} = damping ratio of short period mode

θ = pitch attitude, deg or rad

θ_c = commanded change in airplane pitch attitude, deg or rad

θ_ε = $(\theta_c-\theta)$, error between commanded pitch attitude and airplane pitch attitude, deg or rad

λ = aperiodic real root magnitude, sec^{-1}

ρ = air density, $slug/ft^3$

σ_i = mean square gust intensity, $i = \alpha, \beta$, deg

τ_L = time constant of pilot's lead element, sec

τ_{pitch} = time constant of pitch command prefilter, sec

τ_{roll} = time constant of roll command prefilter, sec

τ_R = time constant of roll mode, sec

τ_s = time constant of spiral mode, sec

LIST OF SYMBOLS (Cont'd)

ϕ	=	bank angle, deg
ω_{BW}	=	bandwidth frequency, rad/sec
ω_d	=	undamped natural frequency of Dutch roll mode, rad/sec
ω_{ph}	=	undamped natural frequency of phugoid mode, rad/sec
ω_{sp}	=	undamped natural frequency of short period mode, rad/sec

SUBSCRIPTS

c.g.	-	center of gravity
DLC	-	direct lift control
e	-	equivalent parameter from equivalent system analysis
g	-	turbulence comronent
G.E.	-	Ground Effect
I	-	inertial quantity
m	-	model quantity
MGP	-	model gear to pilot
MGR	-	model gear to TIFS radar altimeter
MP or PM	-	model quantity at pilot station
MTCG	-	model quantity transformed to TIFS c.g.
P	-	quantity at pilot station
TIFS or unsubscripted	-	TIFS quantity at its c.g.
WH	-	model wheel height
m c.g.	-	model center of gravity
stab	-	stability axis

Section 1
INTRODUCTION

The objective of this in-flight research program,utilizing the Air Force Wright Aeronautical Laboratory/Calspan Total In-Flight Simulator (TIFS), was to obtain data applicable to Flight Phase Category C operation of Class III airplanes, i.e., approach and landing task for very large (one million pound),low-load factor airplanes. The experiment was to provide data on the following factors:

- Minimum short period dynamics
- The need for absolute n/α limits
- Effect of normal acceleration cues
- Augmentation system bandwidth
- Control system time delay and phase shift limits
- Multi-loop control in landing
- Lateral acceleration tolerable to pilot
- Demonstration of lateral-directional augmentation concept

Two Calspan evaluation pilots participated in this program with one pilot evaluating all of the test configurations and the second pilot evaluating approximately one-half of the test configurations.

Pilot comments and ratings were recorded in flight. This data is considered as the principal data obtained from this program. In addition, model responses and data pertinent to trajectory analysis were recorded on board during the performance of the evaluation task.

To gather this data on the flying qualities of very large aircraft in an organized fashion, the configurations evaluated were arranged in the following manner.

Three different basic pilot-aircraft models were generated to evaluate pilot position versus instantaneous center of pitch rotation. The

aerodynamics and control systems of all of these configurations were essentially the same except for the value of Z_{δ_e}, or lift due to elevator deflection, which was used to shift the center of rotation. The three basic configurations were:

- Long Aft Tail - a generic conventionally designed aircraft.
- Canard - pitching moment controller forward, shifting the center of rotation aft, similar to a slender arrow-wing supersonic cruise design with a canard.
- Short Aft Tail - a generic delta wing design with elevons for pitch and roll control, shifting the center of rotation forward of the pilot, similar to the space shuttle orbiter design.

Combined with the three basic configurations were two different types of pitch augmentation systems: an angle of attack feedback system and a pitch rate feedback system. Control system gains were varied to augment the statically unstable basic airframe toward Level 1 handling qualities.

Included in the command paths were different levels of extra transport delays (representative of digital control systems) and first order prefilters (representative of structural filters).

Low-maneuverability configurations (low n_z/α) were evaluated by reducing the lift curve slope for the Long Aft Tail configuration with the angle of attack augmentation system.

In the lateral-directional evaluations, two values of roll-mode time constants were combined with various levels of roll command path delays and prefilters as in the pitch axis. In addition, different vertical pilot positions were evaluated to investigate lateral acceleration effects.

Aeroelastic effects were not simulated in the configuration models.

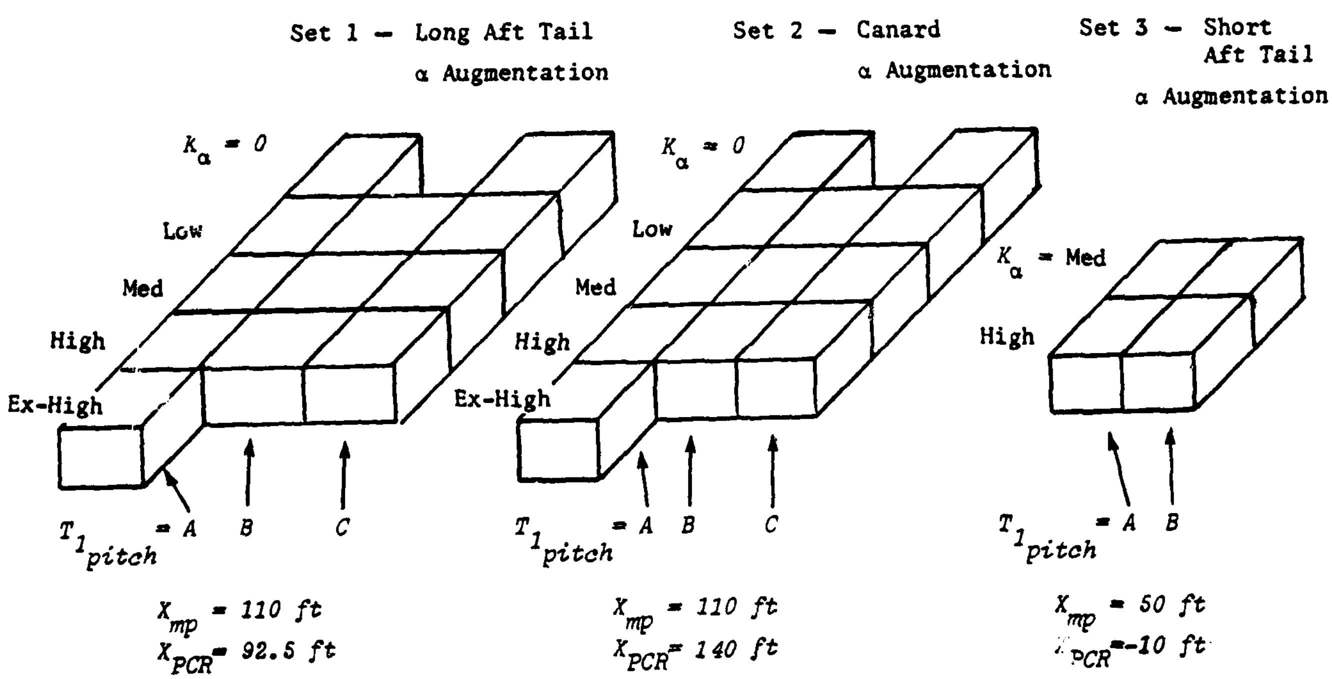
A more detailed description of the configurations which were evaluated are outlined and illustrated in Section 2 along with other details of the experiment design. Section 3 presents the mechanization of the experiment including the description of the TIFS setup. Section 4 presents the results of the program, including data collected and analysis. Section 5 contains the conclusions.

Section 2
EXPERIMENT DESIGN

2.1 CONFIGURATION DESCRIPTION

This flight research program consisted of nine sets of configurations which are outlined and illustrated by the following discussion and diagrams.

Configuration sets 1, 2, and 3 were intended to explore the interactions of basic configuration factors together with an angle of attack augmentation loop only. The α augmentation system is shown in Figure 1. The α signal used was an inertial quantity which eliminated turbulence effects on the feedback signal. The α feedback gain was varied, along with the effective time delays in the pilot's command path to the elevator. These configuration sets are illustrated by the following diagrams.



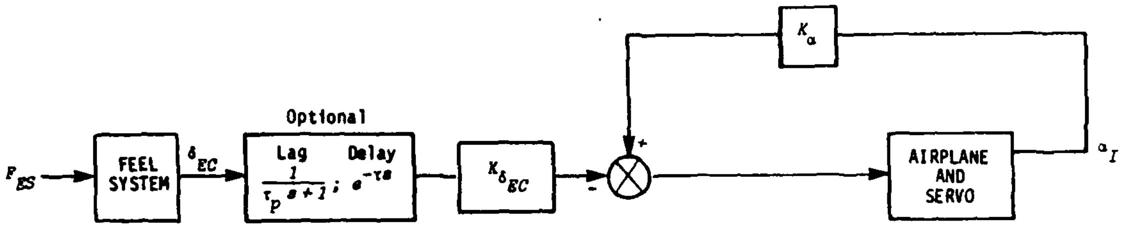


Figure 1. ANGLE OF ATTACK AUGMENTATION

Some of the terms used in these diagrams and in the body of the report are defined below:

$T_{1_{pitch}}$ - notation used to define the effective time delay of the TIFS model following system and the optional elements inserted into the command path. The effective time delay of these portions of the total system is defined by the maximum slope intercept method described in Appendix V-B.

$T_{1_{pitch}} = A$ - nominal effective time delay of the TIFS model following delay in pitch (.06 sec).

$= B$ - "A" delay (.06 sec) plus first order prefilter lag ($\tau_{pitch} = .111$) such that T_1 for these two elements was $T_1 = .13$ sec.

$= C$ - "B" delay plus transport delay (.07 sec) such that T_1 for the three elements was .20 sec.

In the data analysis, the total effective time delay is designated $t_{1_{pitch}}$ and includes the effective delay of the feel system , model surface servo, airplane model and control system.

X_{mp} and X_{PCR} refer to the pilot position with respect to the center of gravity and center of rotation, respectively, for each configuration. These are discussed in detail later in this section.

The set of stability derivatives used to represent the unaugmented airframe were determined from numbers typical of the C-5A and 747-type airplane with an aft c.g. location (Reference 1). The airplane mean aerodynamic chord, wing span, moments of inertia, pilot position and mass were scaled up to the one million pound level. The scaling laws were based on holding wing loading constant ($W/S = 110\ lb/ft^2$, $n_z/\alpha = 4.15\ g/rad$). The maximum lift

coefficient was also not changed, keeping touchdown and approach speeds the same. Since the wing area was scaled up proportionally with the weight, the reference chord and span were increased by the square root of the weight increase. The moments of inertia were increased by the weight ratio squared.

The nondimensional stability and control derivatives for each of the three basic configurations (Long Aft Tail, Canard, and Short Aft Tail) were kept constant except those which affected the instantaneous center of rotation for pitch inputs. The initial normal acceleration due to a pitch input at the location ℓ_x along the X-body axis can be defined as:

$$n_z(0) = \frac{1}{g}\left[\frac{Z_{\delta_e}}{M_{\delta_e}+Z_{\delta_e}M_{\dot{w}}} - \ell_x\right]\dot{q}(0)$$

where ℓ_x is the point of interest along the X-body axis. At the center of rotation (ℓ_{CR}), $n_z(0) = 0$. Therefore,

$$\ell_{CR} = \frac{Z_{\delta_e}}{M_{\delta_e}+Z_{\delta_e}M_{\dot{w}}}$$

Using the above relation and holding M_{δ_e} constant for all configurations, Z_{δ_e} was varied to obtain the desired centers of rotation for each configuration. The nominal lift curve ($C_{L_0} + C_{L_\alpha}\alpha$) had to be modified slightly to keep the trim angle of attack and n_z/α constant. The quadratic drag polar ($C_{D_0} + C_{D_\alpha}\alpha + C_{D_\alpha}\alpha^2$) was chosen to put the aircraft just barely on the back side of the power-required curve at 150 KEAS, the trim speed. The dimensional data and stability derivatives are presented in Section 2.2, and

$$0.004 \leq d\gamma/dV \leq 0.011 \text{ deg/kt}.$$

The actual pilot location in the fuselage for each airplane is defined in Table 1 and graphically shown in Figure 2. The vertical dimension in the body axes system has been varied in each configuration such that the height of the pilot above the X-stability axis was constant at $Z_{sp} = -18$ *ft*. This was done to keep the lateral acceleration environment at the model cockpit and the eye height at simulated touchdown constant.

TABLE 1

PILOT POSITION WITH RESPECT TO MODEL C.G. AND PITCH CENTER OF ROTATION (Body axis, ft)

X_{mp} = X distance from model C.G. to pilot

X_{PCR} = X distance from pitch center of rotation to pilot

Configuration	X_{mp}	X_{PCR}
Base Long Aft Tail	110	92.5
Long Aft (Pilot @ 50')	50	32.5
Base Canard	110	140.0
Canard (Pilot @ 50')	50	80.0
Base Short Aft Tail	50	-10.0
Short Aft (Pilot @ 70')	70	10.0
Short Aft (Pilot @ 110')	110	50.0

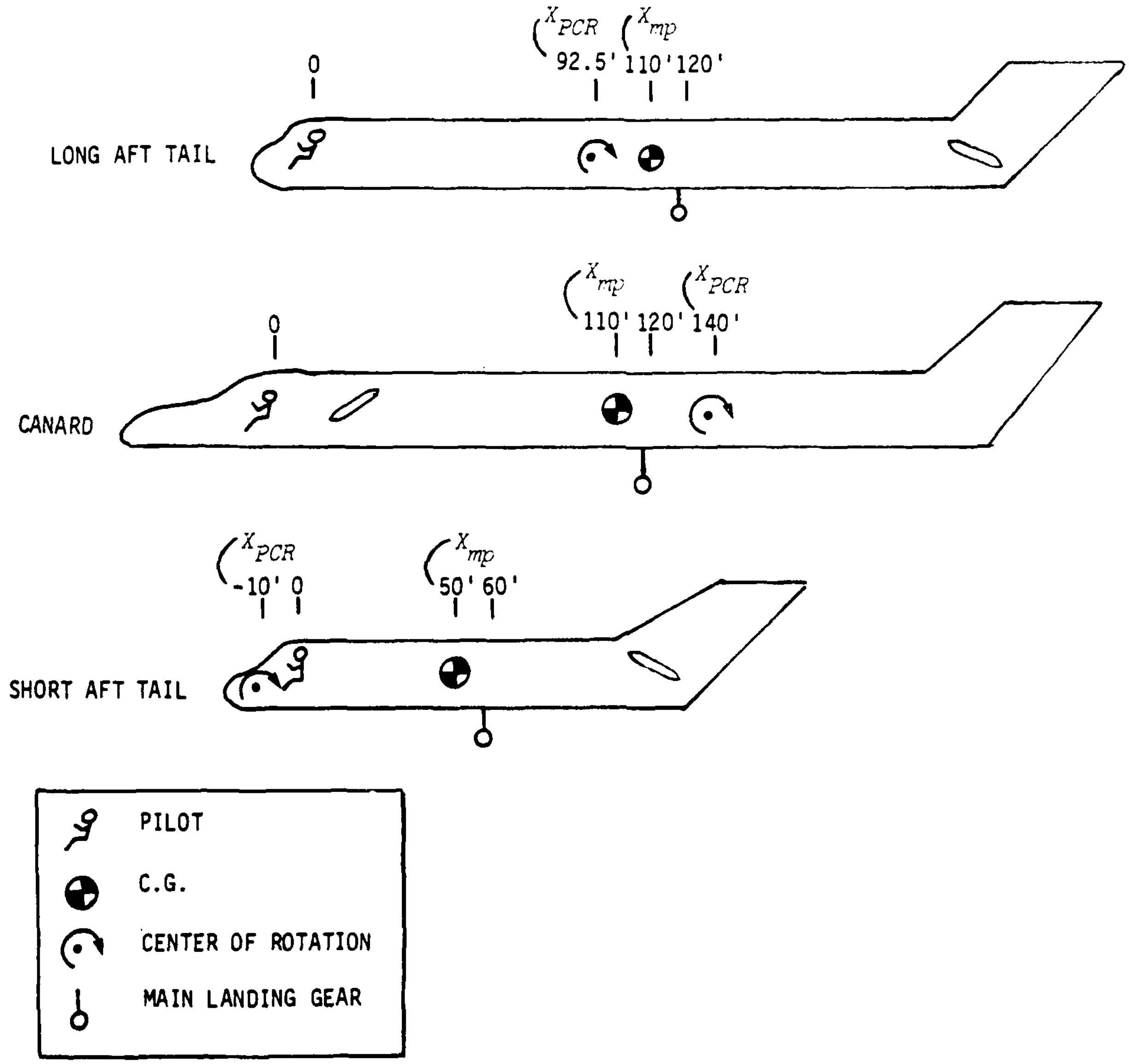


Figure 2. RELATIVE LOCATIONS OF PILOT, C.G., CENTER OF ROTATION, AND MAIN LANDING GEAR OF VARIOUS BASE CONFIGURATIONS

The pitch damping of the base unaugmented airplanes was adequate; only α feedback was required to augment the airplanes toward Level 1 short period dynamics. The K_α gain was chosen such that the nominal dynamics were, using ω_{sp}^2 from Appendix I complex characteristic roots and nominal n_z/α for planning(Equivalent system values were not available initially),

$K_\alpha = 0$	Time to double amplitude for unstable root was 4 seconds.
K_α = Low	One real root at origin, approximately
K_α = Medium	$\omega_{sp}^2 \Big/ \frac{n_z}{\alpha} = .096$ — Level 2 and 3 boundary for $n_z/\alpha = 4.15$ g/rad.
K_α = High	$\omega_{sp}^2 \Big/ \frac{n_z}{\alpha} = .16$ — Level 1 boundary for $n_z/\alpha = 4.15$ g/rad.
K_α = Extra-High	$\omega_{sp}^2 \Big/ \frac{n_z}{\alpha} = .24$ — in Level 1 region for $n_z/\alpha = 4.15$ g/rad.

Actual control system parameters are presented in Section 2.2. Figure 3 shows where these configurations appear with respect to the MIL-F-8785C short period requirements. Equivalent system analysis was performed on the configurations after the flight program was completed,and revised values for the equivalent short-period frequencies were obtained. This analysis is presented in Appendix V-A.

Configuration sets 4, 5 and 6 were a partial repeat of sets 1, 2, and 3, but with the α augmentation system replaced by pitch rate augmentation plus integral path in the forward loop. See Figure 4 for the control system design. This control system had two extra features. One was an angle of attack limiter which started adding pitch down commands when the angle of attack increased beyond a chosen value. The other was a pitch compensator to keep the nose level in a turn without requiring pilot inputs. Since this latter system required a division by cos ϕ which becomes very small at large bank angles, it was limited to bank angles of less than 45 degrees($L\phi$). There was also a limiter on the total pitch rate commanded. This was a function of true airspeed, pitch attitude and bank angle and was used to limit the maximum load factor (n_L). This limiter was not implemented during the evaluations. It was, however, programmed and tested at a load factor of 1.3 g's in the checkout phase of the flight program. All of the extra features in the q augmentation system worked properly and reduced pilot workload in these configurations.

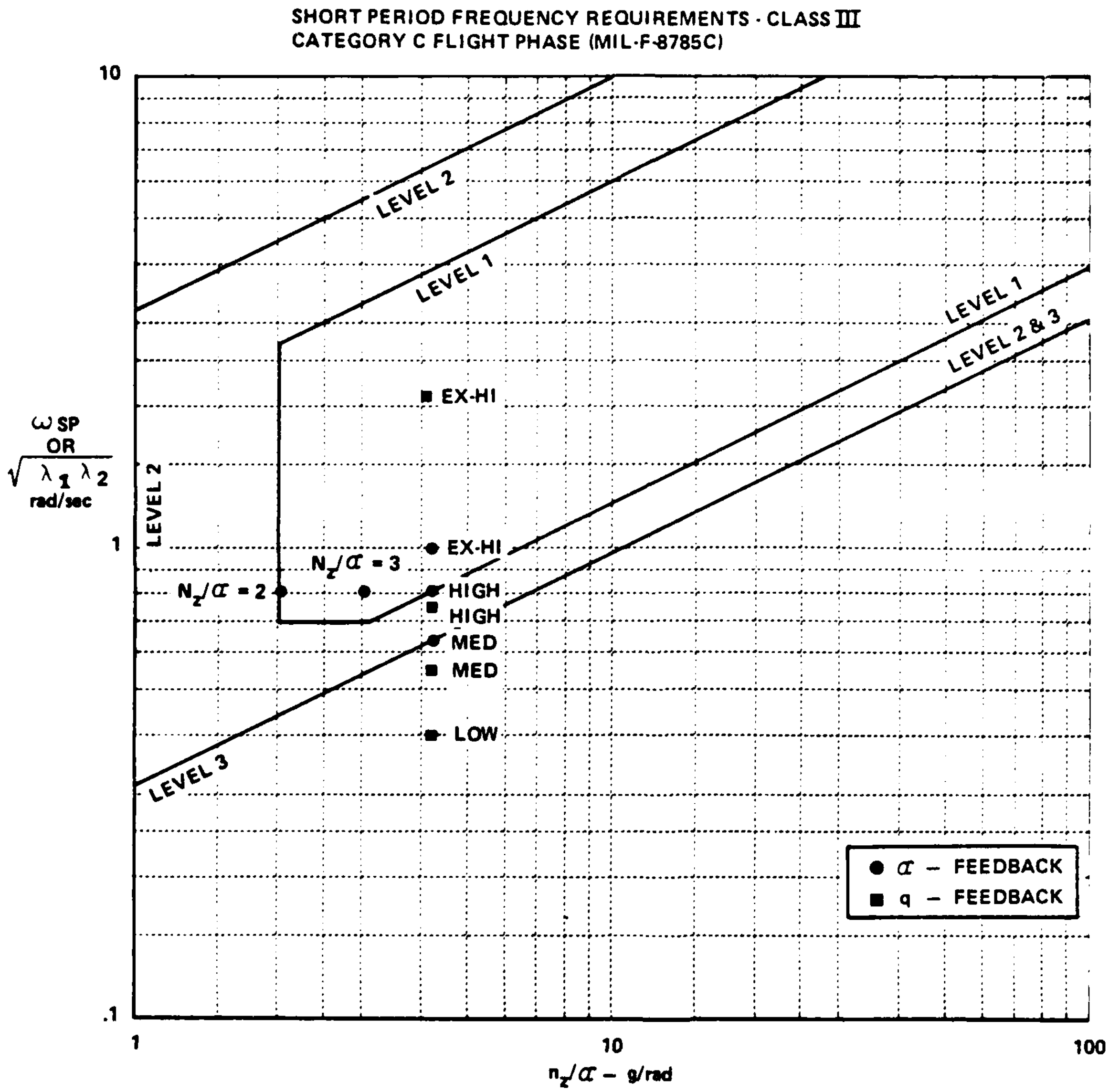
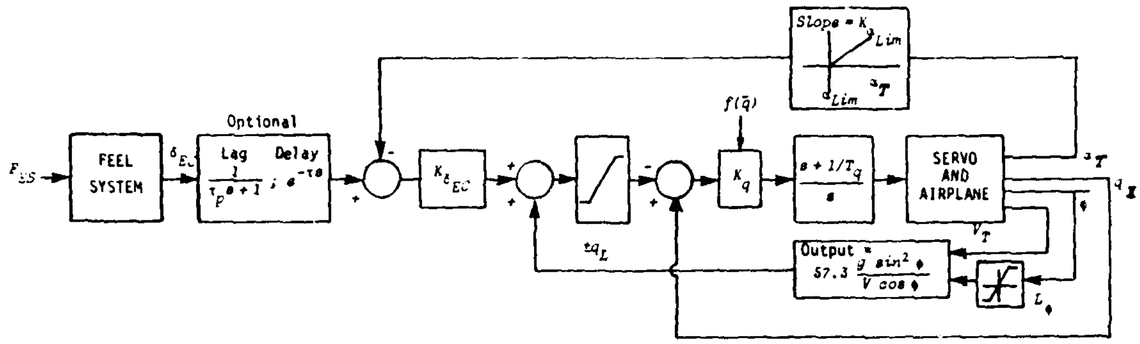


Figure 3. AUGMENTATION LEVELS VS ω_{SP} REQUIREMENTS-NOMINAL ROOTS



$\pm q_L = -\dfrac{g}{V_T}\,[\pm n_L + \cos\theta \ \cos\phi]$, n_L set at $1.3g$ just to check operation in tests, not used in evaluations

L_ϕ ~ Limit bank angle for which elevator is compensated for level turn (± 45 deg)

K_q ~ Loop gain establishes dynamics, function of $\bar{q}$

$K_{\delta_{e_c}}$ ~ Command gain, set by pilot

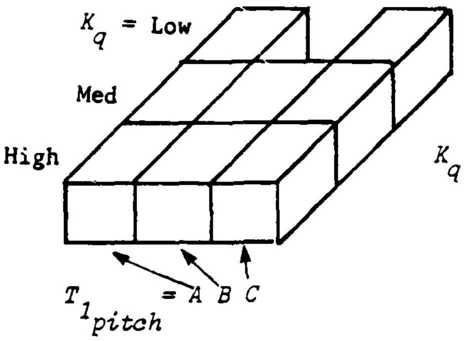
$\dfrac{1}{T_q}$ ~ Integral/Proportional Ratio Influence Augmented Dynamics

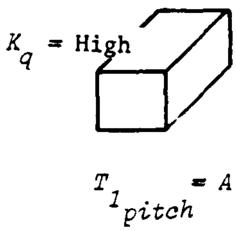
$\alpha_T = \alpha_I + \alpha_g$

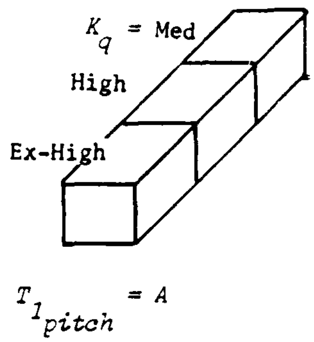
Figure 4. PITCH RATE AUGMENTATION SYSTEM

The q augmentation configuration sets are illustrated by the following diagrams:

Set 4 — Long Aft Tail q augmentation	Set 5 — Canard q Augmentation	Set 6 — Short Aft Tail q Augmentation







X_{mp} = 110 ft.	X_{mp} = 110 ft.	X_{mp} = 50 ft.
X_{PCR} = 97.5 ft.	X_{PCR} = 140 ft.	X_{PCR} = -10 ft.

The q augmentation parameters (K_q and T_q) on Figure 4 were selected to give augmented dynamics analogous in an "equivalent system" sense to the short period dynamics of the α augmented configurations of sets 1, 2, and 3. The K_q gain was inversely proportional to dynamic pressure, $\bar{q}$, to keep the dynamics constant when speed changed. The gain calculations were done before the equivalent system parameters of Appendix V-A were obtained. Specifically, the value for T_q was arbitrarily set at 1 second and the K_q gain varied until the pitch rate time history from a step input reached a maximum at the same time as that for the equivalent α augmented configuration. Actual control system parameters are presented in Section 2.2. Figure 3 shows where these configurations appear on the MIL-F-8785C short period requirements. Equivalent system analyses of these configurations are presented in Appendix V-A.

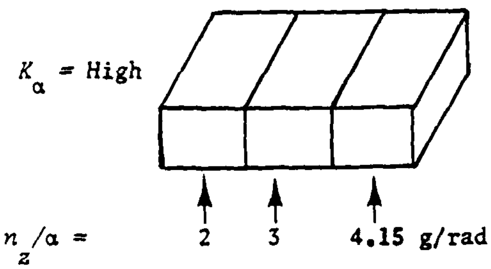
In addition to the above configurations, which were flown at their respective nominal pilot positions, a few extra evaluations were flown with the pilot position shifted. This was done to gather data on the effect of initial

normal acceleration and altitude cues on the pilot. These were all run with $T_{1_{pitch}} = A$:

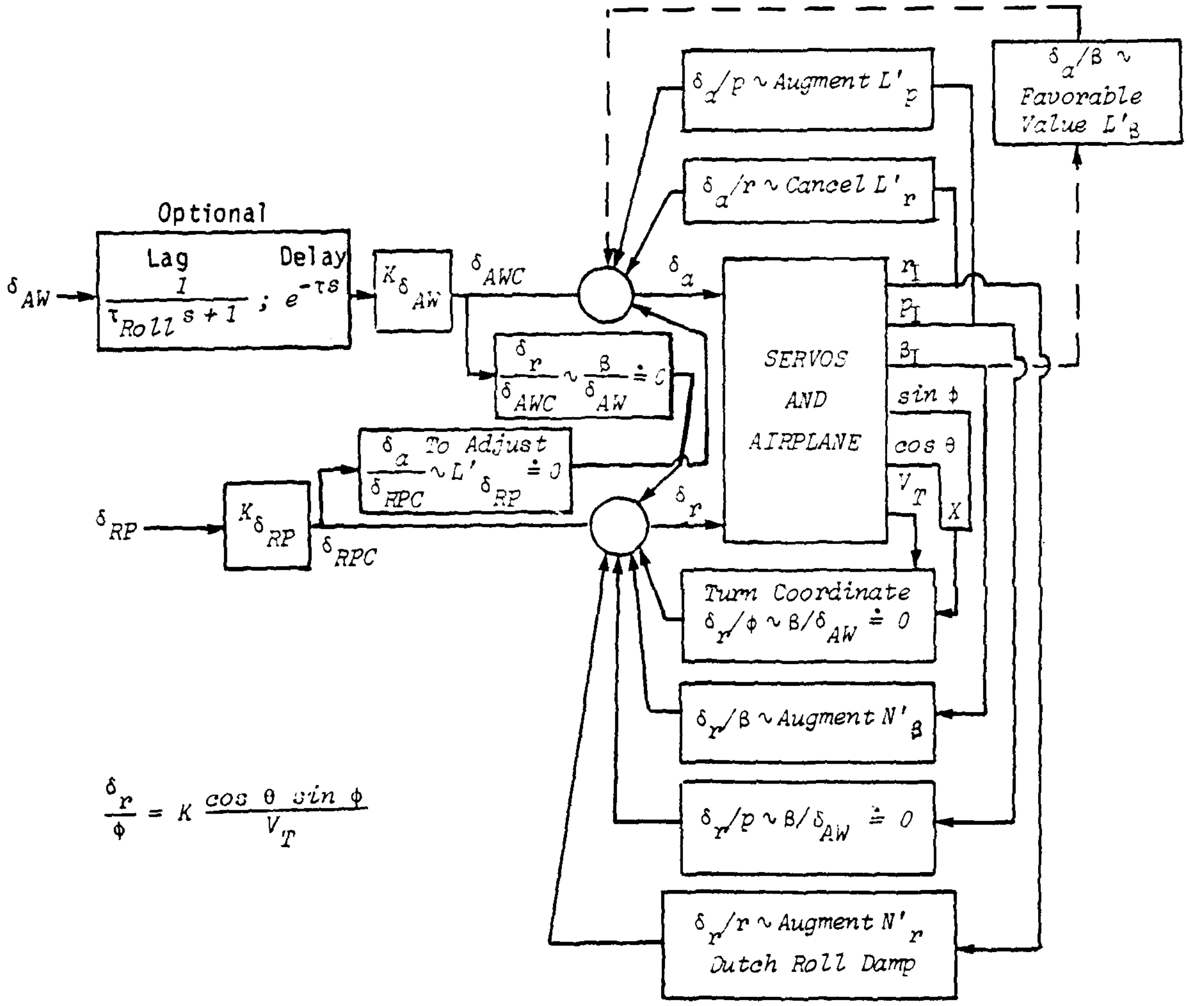
Long Aft Tail, High q, $X_{mp} = 50'$, $X_{PCR} = 32.5'$
Canard Aft Tail, High q, $X_{mp} = 50'$, $X_{PCR} = 80'$
Short Aft Tail, High q, $X_{mp} = 70'$, $X_{PCR} = 10'$
Short Aft Tail, High q, $X_{mp} = 110'$, $X_{PCR} = 50'$

Configuration set 7 was intended to test the validity of the requirements for minimum n_z/α limits in the MIL-F-8785C requirements. These configurations were achieved by rotating the C_L versus α curve about the trim C_L and by revising the C_D versus α curve such that the C_D versus C_L curve was common for all three configurations. This avoided complications relating to extreme backside of the power required curve operations that might have otherwise occurred.

Set 7 — Long Aft Tail, High α Augmentation
$T_{1_{pitch}} = A$, n_z/α variation



Configuration set 8 was designed to investigate the pilot's tolerance to lateral acceleration at the cockpit. The acceleration environment during turning and rolling maneuvers was modified through variations in the roll damping and roll command gain and the height of the pilot above the X stability axis. The lateral-directional augmentation was set up such that the airplane rolled and turned in response to roll controller commands without inducing sideslip. The control system design is presented in Figure 5 . Actual control system parameters are presented in Section 2.2. The nominal airplane was the Long Aft Tail configuration with good pitch dynamics — High q augmentation with $T_{1_{pitch}} = A$, for all of the lateral-directional evaluations.

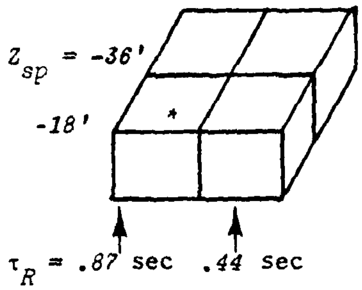


Augments primary derivatives, cancels coupling, uses bank angle for turn coordination, feeds back β_I measured as a pseudo inertial signal.

Figure 5. LATERAL - DIRECTIONAL CONTROL SYSTEM

The roll mode time constant and pilot position matrix was:

Set 8 — Lateral Acceleration versus
τ_R and Z_{sp}, all at $T_{1_{roll}} = A$



$-Z_{sp}$ = height of pilot above X-stability axis, ft
τ_R = roll mode time constant, sec

* This is the baseline Long Aft Tail, $T_{1_{pitch}} = A$, High q configuration of Set 4.

Configuration set 9 was designed to investigate the effects of time delay and prefilters in the pilot's roll command channel. The effective time delay in the roll channel, $T_{1_{roll}}$ was implemented as follows:

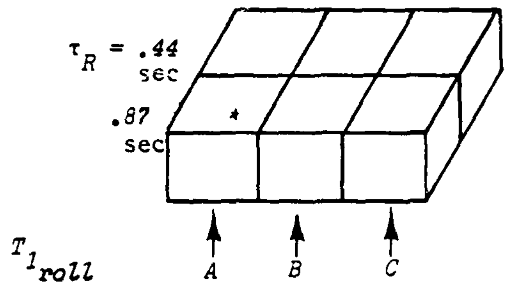
$T_{1_{roll}} = A$ - Nominal effective time delay of the TIFS model-following delay in roll (.12 sec).

$= B$ - "A" delay (.12 sec) plus first order prefilter lag (τ_{roll} = .21) such that T_1 of these two elements was T_1 = .20 sec.

$= C$ - "B" delay (.20 sec) plus transport delay (.08 sec) such that T_1 of these three elements was T_1 = .28 sec.

In the data analysis, the total effective time delay is designated $t_{1_{roll}}$ and includes the effective delay of the feel system, model surface servo and airplane model.

Set 9 — Lateral-directional time delay and lag variations



*This is the baseline Long Aft Tail, $T_{1_{pitch}} = A$, High q configuration of Set 4.

The lateral-directional augmentation system illustrated in Figure 5 was also used to achieve good lateral-directional flying qualities for all the configurations for which lateral-directional parameters were not the primary focus of the evaluations. It used the τ_R = .87 sec gains with $T_{1_{roll}} = A$ and set the pilot at the lower position, Z_{sp} = -18 ft.

A configuration set 10 was planned to explore the flying qualities of large space shuttle-type vehicles performing unpowered approaches and landings and to determine how much the pitch flying qualities of such a vehicle would be degraded by time delay in the pitch command channel. Due to the lack of time and funds, this experiment was not carried out. However, the results of the Short Aft Tail model evaluations are applicable to large shuttle configurations due to its similarity in normal acceleration response, i.e., with the pilot near or aft of the pitch center of rotation. In addition, an extra configuration with the approximate shuttle delay (an equivalent time delay of $T_{1_{pitch}}$ = .35 seconds plus feel system) was evaluated. This is the $T_1 = C$ level plus an extra .11 sec transport delay. The use of a direct lift control device for precise flight path control was also investigated with the Short Aft Tail configuration.

Aerodynamic, control, and feel system representation of each of the evaluated configurations are presented in the next subsection. Transfer function representations of each of the evaluated configurations are presented in Appendix I. Step input time histories for pitch, roll and yaw commands for each of the evaluated configurations are presented in Appendix II.

2.2 MODEL EQUATIONS OF MOTION, AERODYNAMICS AND CONTROL SYSTEM PARAMETERS

The equations of motion programmed in the TIFS model computer were:

Force Equations (all angular terms in degrees)

$$\dot{V}_I = -\frac{\bar{q}S}{m}(C_D \cos\beta_I - C_y \sin\beta_I) - g\sin\gamma + \frac{T}{m}\cos\alpha_I \cos\beta_I$$

where: $\sin\gamma_I = \cos\beta_I(\cos\alpha_I \sin\theta - \sin\alpha_I \cos\theta\cos\phi) - \sin\beta_I \cos\theta\sin\phi$

$$\dot{\alpha}_I = -\frac{(57.3)\bar{q}SC_L}{mV_I\cos\beta_I} + \frac{(57.3)g}{V_I\cos\beta_I}[\cos\theta\cos\phi\cos\alpha_I + \sin\theta\sin\alpha_I]$$

$$+ q_I - \tan\beta_I[p_I\cos\alpha_I + r_I\sin\alpha_I]$$

$$-\frac{T\sin\alpha_I(57.3)}{mV_I\cos\beta_I}$$

$$\alpha_I = \sin^{-1}\frac{V_{Z_I}}{V_I\cos\beta_I} = \int\dot{\alpha}_I dt$$

$$\alpha_T = \alpha_I + \alpha_q = \alpha$$

$$\dot{\beta}_I = \frac{(57.3)\bar{q}S}{mV_I}(C_y\cos\beta_I + C_D\sin\beta_I)$$

$$+\frac{(57.3)g}{V_I}[\cos\theta\cos\beta_I\sin\phi - \sin\beta_I(\cos\theta\cos\phi\sin\alpha_I$$

$$- \sin\theta\cos\alpha_I)]$$

$$+ p_I\sin\alpha_I - r_I\cos\alpha_I$$

$$-\frac{T\cos\alpha_I\sin\beta_I(57.3)}{mV_I}$$

$$\beta_I = \sin^{-1}\frac{V_{y_I}}{V_I} = \int \dot{\beta}_I dt$$

$$\beta_T = \beta_I + \beta_g = \beta$$

Moment Equations (Body axes)

$$\dot{q}_I = \frac{(57.3)\bar{q}S\bar{c}}{I_{yy}}\,[C_m] + \left(\frac{I_{zz} - I_{xx}}{I_{yy}}\right)\frac{p_I r_I}{57.3} + \frac{I_{xz}}{I_{yy}}\left(\frac{r_I^2 - p_I^2}{57.3}\right)$$

$$\dot{p}_I = \frac{(57.3)\bar{q}Sb}{I_{xx}}\,[C_\ell] + \left(\frac{I_{yy} - I_{zz}}{I_{xx}}\right)\frac{q_I r_I}{57.3} + \frac{I_{xz}}{I_{xx}}\left(\dot{r}_I + \frac{p_I q_I}{57.3}\right)$$

$$\dot{r}_I = \frac{(57.3)\bar{q}Sb}{I_{zz}}\,[C_n] + \left(\frac{I_{xx} - I_{yy}}{I_{zz}}\right)\frac{q_I p_I}{57.3} + \frac{I_{xz}}{I_{zz}}\left(\dot{p}_I - \frac{q_I r_I}{57.3}\right)$$

The nondimensional aerodynamic coefficients were defined by the following equations:

$$C_D = C_{D_o} + C_{D_\alpha}\alpha_T + C_{D_{\alpha^2}}\alpha^2 + C_{D_{\delta_e}}\delta_e + C_{D_{G.E.}}\ \mathrm{F(h)}$$

$$C_L = C_{L_o} + C_{L_\alpha}\alpha_T + C_{L_{\delta_e}}\delta_e + C_{L_{\delta_{DLC}}}\delta_{DLC} +$$

$$\frac{\bar{c}}{2V}(C_{L_q}q + C_{L_{\dot{\alpha}}}\dot{\alpha}) + C_{L_{G.E.}}\ \mathrm{F(h)}$$

$$C_y = C_{y_\beta}\beta_T + C_{y_{\delta_a}}\delta_a + C_{y_{\delta_r}}\delta_r + \frac{b}{2V}(C_{y_p}p + C_{y_r}r)$$

$$C_\ell = C_{\ell_\beta}\beta + C_{\ell_{\delta_a}}\delta_a + C_{\ell_{\delta_r}}\delta_r + \frac{b}{2V}(C_{\ell_p}p + C_{\ell_r}r)$$

$$C_m = C_{m_o} + C_{m_\alpha}\alpha + C_{m_{\delta_e}}\delta_e + \frac{\bar{c}}{2V}(C_{m_q}q + C_{m_{\dot\alpha}}\dot\alpha)$$

$$+ C_{m_{G.E.}} F(h)$$

$$C_n = C_{n_\beta}\beta + C_{n_{\delta_a}}\delta_a + C_{n_{\delta_r}}\delta_r + \frac{b}{2V}(C_{n_p}p + C_{n_r}r)$$

The constant physical characteristics for all of the configurations are listed below:

Constant Large Aircraft Characteristics

Weight (W)	= 1,000,000 lb
Mass (m)	= 31,085. slugs
Wing area (S)	= 9,060 ft^2
Span (b)	= 258 ft
Chord ($\bar{c}$)	= 35.7 ft
I_{xx}	= 55,000,000 slug-ft^2
I_{yy}	= 78,000,000 slug-ft^2
I_{zz}	= 127,000,000 slug-ft^2
I_{xz}	= 0 slug-ft^2

All configurations trimmed at:

V	= 150 knots equivalent airspeed
V	= 253.2 ft/sec, sea level
$\bar{q}$	= $1/2\,\rho V^2$ = 76.29 lb/ft
$C_{L_{trim}}$	= 1.45
$C_{D_{trim}}$	= .16
$Thrust_{trim}$	= 110,590 lb
α_{trim}	= 4 degrees
$\delta_{e_{trim}}$	= 0

Elevator, aileron, rudder first-order servos: $\frac{1}{.05s+1}$

The stability and control derivatives for the specific configurations were:

Longitudinal Non-Dimensional Derivatives (All angular coefficients in terms of degrees)

	Unaugmented Long Aft Tail	Unaugmented Canard	Unaugmented Short Aft Tail
C_{L_o}	1.04	.98	1.08
C_{L_α}	.103	.117	.0916
$C_{L_{\delta_e}}$	.0065	.0114	.0217
$C_{L_{\delta_{DLC}}}$	0.	0.	.003 (1/percent)
C_{D_o}	.115	.115	.115
C_{D_α}	.0093	.0093	.0093
$C_{D_{\alpha^2}}$	.00046	.00046	.00046
C_{m_o}	-.0643	-.0643	-.0643
C_{m_α}	.01607	.01607	.01607
$C_{m_{\dot\alpha}}$	-.10	-.10	-.10
C_{m_q}	-.39	-.39	-.39
$C_{m_{\delta_e}}$	-.026	.026	-.026

Reduced n_z/α for Long Aft Tail (only changes listed)			
n_z/α g/rad	4.15 (Base)	3	2
C_{L_o}	1.04	1.15	1.26
C_{L_α}	.103	.0747	.0464
C_{D_o}	.115	.127	.140
C_{D_α}	.0093	.0068	.0042
$C_{D_{\alpha^2}}$	.00046	.00034	.00021

Lateral-Directional Non-Dimensional Derivatives (All angular coefficients in terms of degrees)

C_{y_β}	-.016
C_{y_p}	0
C_{y_r}	0
$C_{y_{\delta_a}}$	0
$C_{y_{\delta_r}}$	.0033
C_{n_β}	.0021
C_{n_p}	-.0023
C_{n_r}	-.0054
$C_{n_{\delta_a}}$	.00014
$C_{n_{\delta_r}}$	-.0019
C_{ℓ_β}	-.0033
C_{ℓ_p}	-.0082
C_{ℓ_r}	.0038
$C_{\ell_{\delta_a}}$	.0014
$C_{\ell_{\delta_r}}$	.00017

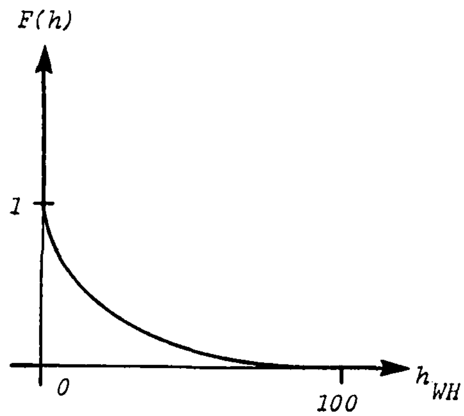
Ground Effect

Typical for large transport aircraft

$$\Delta C_{L_{GE}} = .07\ F(h)$$
$$\Delta C_{D_{GE}} = .016\ F(h)$$
$$\Delta C_{m_{GE}} = -.0038\ F(h)$$

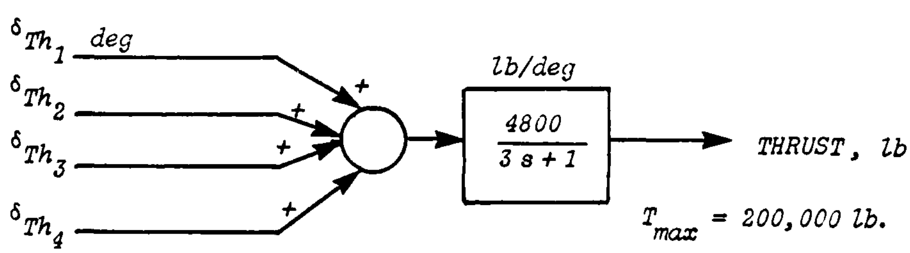
where $F(h)$ is defined from the following:

h_{WH} (ft)	$F(h)$
> 100	0.
90	.02
80	.04
70	.06
60	.08
50	.10
40	.14
30	.20
20	.32
10	.50
0	1.00



Thrust

The symmetric thrust acted through the center of gravity of the model aircraft, thus producing no pitching moment. Thrust was commanded collectively through four throttle handles which produced thrust lagged by a three-second first-order filter.



The control system gains were:

Longitudinal

Alpha Augmentation $K_\alpha = \delta_e/\alpha$, deg/deg	Long Aft Tail K_α	Canard K_α	Short Aft Tail K_α
Low (pole at origin)	.61	.62	---
Med $\left(\frac{\omega^2}{n_z/\alpha} = .096\right) \frac{\text{rad}}{\text{sec}^2\text{g}}$	.90	.88	.85
High $\left(\frac{\omega^2}{n_z/\alpha} = .15\right)$	1.35	1.36	1.25
Extra High $\left(\frac{\omega^2}{n_z/\alpha} = .24\right)$	2.1	2.3	---

High Alpha Augmentation for Reduced n_z/α Configurations Long Aft Tail	K_α	$\omega_{sp}^2 / n_z/\alpha$
Baseline $n_z/\alpha = 4.15$ g/rad	1.35	.15 $\frac{\text{rad}}{\text{sec}^2\text{g}}$
$n_z/\alpha = 3$	1.45	.21
$n_z/\alpha = 2$	1.60	.31

Pitch Rate Augmentation $K_q = \frac{\delta_e}{q}$, deg/deg/sec $T_q = 1$ sec	Long Aft Tail		Canard		Short Aft Tail	
	$K_q(\bar{q})$	$K_q\left(\begin{matrix}@150\ KIAS\\ \bar{q} = 76.3\end{matrix}\right)$ psf	$K_q(\bar{q})$	$K_q\left(\begin{matrix}@150\ KIAS\\ \bar{q} = 76.3\end{matrix}\right)$	$K_q(\bar{q})$	$K_q\left(\begin{matrix}@150\ KIAS\\ \bar{q} = 76.3\end{matrix}\right)$ psf
Low	$45.3/\bar{q}$	.6	----	----	$42/\bar{q}$	.55
Medium	$99.2/\bar{q}$	1.3	----	----	$80.1/\bar{q}$	1.05
High	$209.8/\bar{q}$	2.75	$214/\bar{q}$	2.81	$190.8/\bar{q}$	2.5
Extra High with $T_q = .5$	----	----	----	----	$397/\bar{q}$	5.2

Alpha Limiting System:

α_{lim} = 6 degrees, equivalent to V = 140 KIAS

$K_{\alpha_{lim}}$ = 2 deg/deg

Lateral-Directional

Feedback Gains	Low Roll Damping (τ_R = .87 sec)	High Roll Damping (τ_R = .44 sec)
δ_a/β	0	0
δ_a/p	-1.3 sec	-5.0 sec
δ_a/r	-1.6 sec	-1.6 sec
δ_a/ϕ	0	0
δ_a/δ_{RPC}	- .125	- .125
δ_r/β	0	0
δ_r/p	-1.285 sec	-1.252 sec
δ_r/r	1.5 sec	1.5 sec
δ_r/ϕ	$-2.945\ \frac{g}{V}$ = -.3742 @ 150 KIAS	$-2.945\ \frac{g}{V}$ = -.3742 @ 150 KIAS
δ_r/δ_{AWC}	- .00895	-.00895

Feel System

In general, the pilots were allowed to select the command gains for each configuration to be evaluated. However, they were normally kept at the nominal values shown below except where noted in the flight/configuration log in Section 4.1.

Pitch Command Gain

$K_{\delta_{EC}}$ (α feedback) = 2.5 deg/in

$K_{\delta_{EC}}$ (q feedback) = 1.25 $\frac{\text{deg/sec}}{\text{in}}$

(pitch gain was negative for Canard configuration)

Roll Command Gain

$K_{\delta_{AW}}$ (τ_R = .87) = 1.5 deg/deg

$K_{\delta_{AW}}$ (τ_R = .44) = 3.0 deg/deg

Yaw Command Gain

$K_{\delta_{RP}}$ =-15. deg/in

NOTE: These are nominal values. See Flight Log in Section 4.1 for values used by each pilot for specific evaluations.

The cockpit controllers consisted of a wheel, column and rudder pedals with the following characteristics:

<u>Pitch</u> –	ω_n (rps)	25.0 or 15.0*
	ζ (–)	.7
	Gradient lbs/in	10.0
	Breakout (lbs)	4.0
	Hysteresis (lbs)	0
<u>Roll</u> –	ω_n (rps)	25.0
	ζ (–)	.7
	Gradient (lbs/deg)	.5
	Breakout (lbs)	2.0
	Hysteresis (lbs)	0
	Max Deflection (deg)	80.0
<u>Yaw</u> –	ω_n (rps)	15.0
	ζ (–)	.7
	Gradient (lbs/in)	100.0
	Breakout (lbs)	3.5
	Hysteresis (lbs)	0

As with the column (Figures 1 and 4) the wheel and rudder pedal feel systems were in series with the control force. Feel servos were commanded by pilot-applied forces. Surface servos were commanded by controller displacement.

*Pilot A flew all configurations with a 25 rad/sec pitch feel system, Pilot B flew most of his configurations at 15 rad/sec and a few at 25 rad/sec as indicated in the Chronological Flight/Configuration Log (Table VI in Section 4.1). Pilot B objected to a feel system chatter that occurred with the 25 rad/sec setting when making large force applications.

Section 3
EXPERIMENT MECHANIZATION

3.1 EQUIPMENT

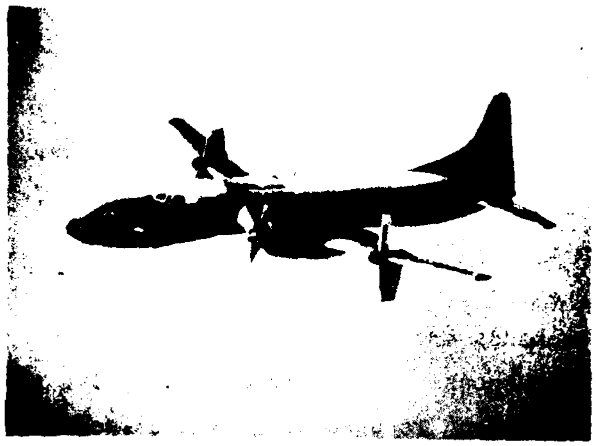
The USAF/Calspan Total In-Flight Simulator (TIFS) was used as the test vehicle in this experiment. TIFS is a highly modified C-131 (Convair 580) configured as a six-degree-of-freedom simulator (Figure 6). It has a separate evaluation cockpit forward and below the normal C-131 cockpit. When flown from the evaluation cockpit in the simulation or fly-by-wire mode, the pilot control commands are fed as inputs to the model computer which calculates the aircraft response to be reproduced. These responses, along with TIFS motion sensor signals, are used to generate feedforward and response error signals which drive the six controllers on the TIFS (Figure 7). The model-following system gains are documented in Appendix VI. The result is a high fidelity reproduction of the motion and visual cues at the pilot position of the model aircraft. A detailed description of the TIFS can be found in Reference 2 .

This experiment made use of the following major features inherent in the TIFS aircraft:

1. Independent control of all six forces and moments by use of elevator, aileron, rudder, throttle, direct lift flaps and side force surfaces.

2. Longitudinal and lateral/directional model-following systems to provide the evaluation pilot with motion and visual cues representative of the simulated aircraft.

3. Separate evaluation cockpit capable of accepting appropriate pilot controls,displays, and copilot assistance. (Occasionally an observer, but never copilot, was present there)



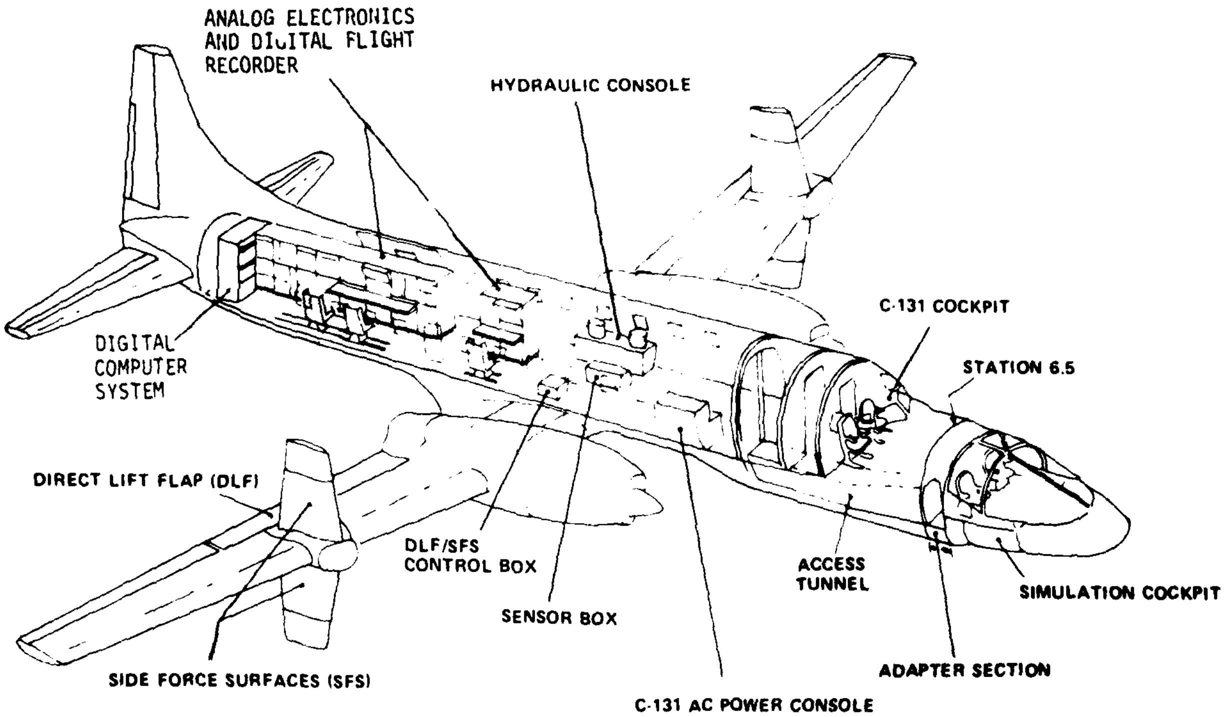


Figure 6. USAF/CALSPAN TOTAL IN-FLIGHT SIMULATOR (TIFS)

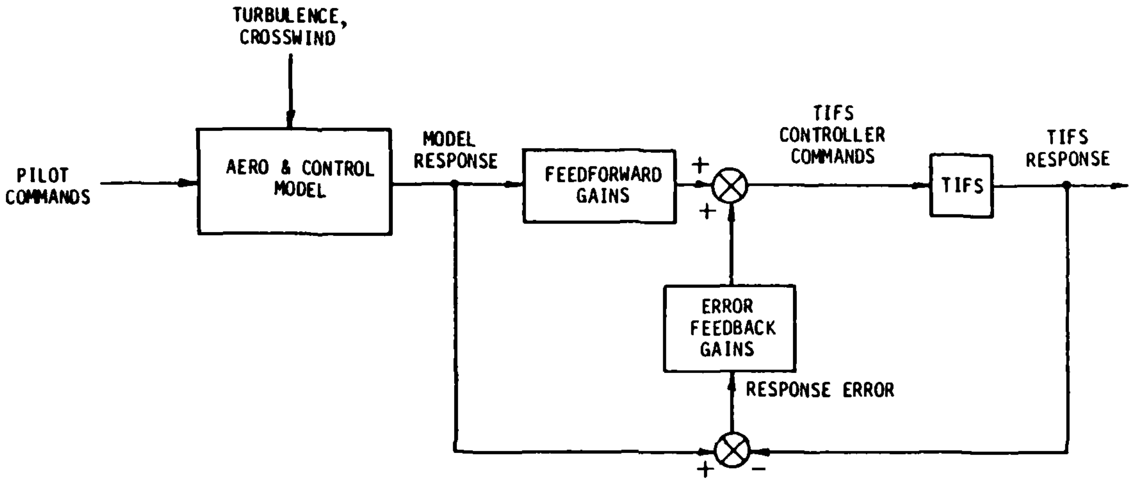


Figure 7. TIFS MODEL FOLLOWING SIMULATION

4. Evaluation cockpit instruments included standard IFR instrument displays featuring an ADI and an HSI as the primary instruments, with angle of attack displayed on an indicator on the right hand side of the HSI and sideslip displayed on an indicator above the HSI. The vertical and horizontal bars on the ADI displayed command information for tracking localizer and glide slope, respectively.

5. Digital magnetic tape recording system to record control inputs and appropriate aircraft responses.

6. Two cassette tape voice recorders for recording evaluation pilot comments, and TIFS crew comments.

7. The capability to simulate artificial or cancel actual crosswinds up to 15 kts incorporated in the model-following system.

8. Turbulence simulated by playing pre-recorded random signals into the model through filters mechanized to produce the proper power spectrum of turbulence (natural turbulence, was measured and added to these signals to improve the model following when rough air was experienced).

9. A signal light located above the ADI and audio signal to indicate simulated touchdown of main landing gear.

10. Adjustable transport time delay circuits, available to simulate time delay in the pilot's commands to the elevator and aileron controls.

11. Digital computing equipment recently installed in the TIFS airplane, to calculate model aerodynamics and evaluate kinematic equations.

3.2 SIMULATION GEOMETRY

The TIFS motion system was configured to reproduce the model's motion at the evaluation pilot's eye point as if the TIFS were positioned as shown in Figure 8. In this sketch, the model is shown in its approximate attitude at touchdown. Despite qualms about the possible effect on pilot rating of not actually touching down, it was decided to preserve the proper geometric relationship between the pilot and main gear at touchdown.

Approaches were made to a simulated touchdown with the evaluation pilot at his proper eye height. The TIFS wheels at this altitude were approximately 29 feet above the ground. Altitude was measured by a radar altimeter mounted on the underside of the TIFS fuselage. Equations relating this measured altitude (h_R) to the model wheel height (h_{WH}) and TIFS wheel height (h_T) are given below.

$$h_T = h_R + 21.3 \sin\theta - 6.7 \cos\theta$$

$$h_{WH} = h_R - X_{MGR} \sin\theta - Z_{MGR} \cos\theta$$

(h_{WH} was altitude called out and displayed to evaluation pilot on his vertical tape). The primary distances of interest are defined in Table II and III.

To obtain responses of the model at the TIFS C.G., a point 33.9 feet aft of the evaluation cockpit, (about which the model following is actually done) the following transformations are used:

$$\dot{V}_{MTCG} = \dot{V}_m + \frac{q_m}{57.3} Z_{MTCG}$$

$$\alpha_{I_{MTCG}} = \alpha_{I_m} - \frac{q_m}{V_m} X_{MTCG}$$

$$\dot{\alpha}_{MTCG} = \dot{\alpha}_m - \frac{\dot{q}}{V_m} \dot{X}_{MTCG}$$

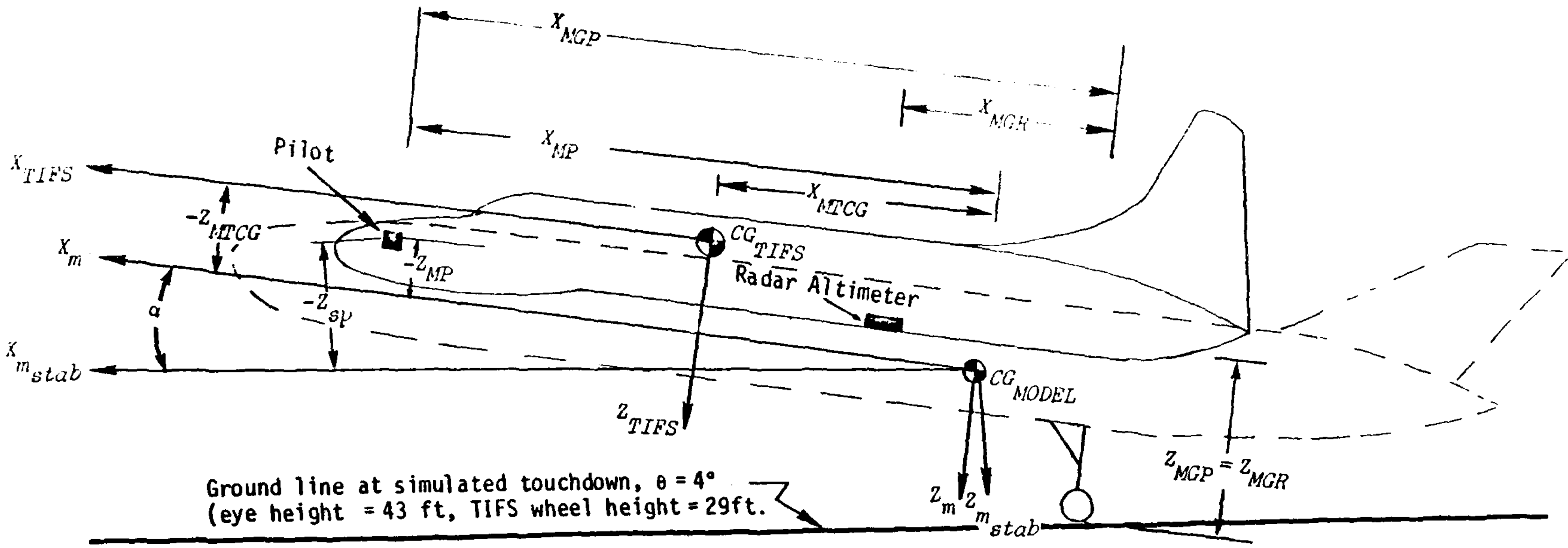


Figure 8. GEOMETRY OF TIFS SUPERIMPOSED ON MODEL

TABLE II

PILOT POSITION

(All in body axes except Z_{SP} in stability axis @ $\alpha = 4^{\circ}$, and in ft)

MP — model C.G. to pilot

$MTCG$ — model C.G. to TIFS C.G.

X_{PCR} — pilot location relative to center of rotation for pitch commands (+) Fwd. (-) Aft

Z_{SP} — pilot location relative to X-stability axis. (-) Above X-axis.

Configuration	X_{MP}	Z_{MP}	X_{MTCG}	Z_{MTCG}	X_{PCR}	Z_{SP}
Base Long Aft Tail (pilot @ 110')	110	-10(Low) -28(High)	76.1	- 7.2 (Low) -25.2 (High)	92.5	-18 (Low) -36 (High)
Long Aft (pilot @ 50')	50	-14.5	16.1	-11.7	32.5	-18
Base Canard (pilot @ 110')	110	-10.0	76.1	- 7.2	140.0	-18
Canard (pilot @ 50')	50	-14.5	16.1	-11.7	80.0	-18
Base Short Aft Tail (pilot @ 50')	50	-14.5	16.1	-11.7	-10.0	-18
Short Aft (pilot @ 70')	70	-13.1	36.1	-10.3	10.0	-18
Short Aft (pilot @ 110')	110	-10.0	76.1	- 7.2	50.0	-18

TABLE III

MODEL WHEEL POSITION

MGR = model gear to TIFS radar altimeter

MGP = model gear to pilot

Configuration	X_{MGP}	Z_{MGP}	X_{MGR}	Z_{MGR}	h_T - TIFS Gear Height @ T.D.	h_p
Long Aft (X_{MP} = 110')	120	30.0	62.4	30.0	29	43
Long Aft (X_{MP} = 50')	60	34.5	2.4	34.5	29	43
Canard (X_{MP} = 110')	120	30.0	62.4	30.0	29	43
Canard (X_{MP} = 50')	60	34.5	2.4	34.5	29	43
Short Aft(X_{MP} = 50')	60	34.5	2.4	34.5	29	43
Short Aft(X_{MP} = 70')	80	33.1	22.4	33.1	29	43
Short Aft(X_{MP} = 110')	120	30.0	62.4	30.1	29	43

$$\Delta n_{z_{MTCG}} = \Delta n_{z_{m_{CG}}} - \frac{\dot{q}_m}{57.3g} X_{MTCG}$$

$$\Delta n_{z_{PM}} = \Delta n_{z_{m_{CG}}} - \frac{\dot{q}_m}{57.3g} X_{MP}$$

$$\beta_{MTCG} = \beta_m + \frac{1}{V_m} (X_{MTCG}\, r_m - Z_{MTCG}\, p_m)$$

$$\dot{\beta}_{MTCG} = \dot{\beta}_m + \frac{1}{V_m} (X_{MTCG}\, \dot{r}_m - Z_{MTCG}\, \dot{p}_m)$$

$$n_{y_{MTCG}} = \frac{\bar{q}SC_{y_m}}{Wt_m} + \frac{1}{57.3g} (X_{MTCG}\, \dot{r}_m - Z_{MTCG}\, \dot{p}_m)$$

$$n_{y_{PM}} = n_{y_{m_{CG}}} + \frac{1}{57.3g} (X_{MP}\, \dot{r}_m - Z_{MP}\, \dot{p}_m)$$

The subscript *MTCG* indicates a model response transformed to the location corresponding to the TIFS C.G.. Once TIFS follows these responses at its own C.G., the pilot's sensed accelerations should also follow even though n_{y_p} and n_{z_p} are not explicitly used in the model following system. This is true because all of the parameters that make up the accelerations ($n_{z_{CG}}$, $n_{y_{CG}}$, $\dot{p}$, $\dot{q}$, $\dot{r}$, V) are matched and the geometry is fixed. Aeroelasticity is ignored.

3.3 EVALUATION COCKPIT CONFIGURATION

The evaluation cockpit was configured as illustrated in Figure 9 . The four throttle levers were active and commanded the total thrust of all four engines on the model without any yawing moment effects, i.e., each throttle lever controlled one fourth of the input to the total thrust computation. This provided a large-airplane feel without added computational complexity.

The cockpit instruments were generally as shown in Figure 10. Not shown in Figure 10 but included on this program were a horizontal meter between the ADI and the HSI displaying sideslip angle and a vertical meter to the right of the HSI displaying angle of attack. Raw glide slope error was displayed as a vertical bug motion on the left side of the ADI. Raw localizer was shown on the localizer needle on the HSI. Rate of climb and radar altitude were displayed on the tape instrument to the right of the ADI.

Figure 9. TIFS SIMULATION COCKPIT

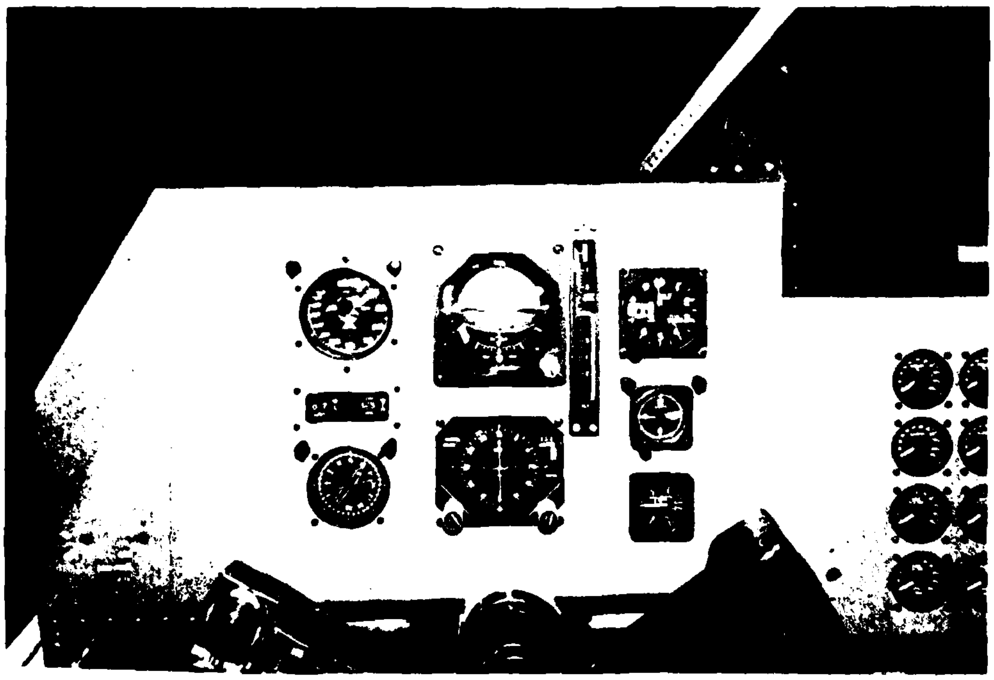


Figure 10. CAPTAIN'S INSTRUMENT PANEL IN EVALUATION COCKPIT

Pitch and roll trim controls were combined in a wheel-mounted thumb switch. The rudder trim control was a switch on the center console.

A Collins flight director, installed in the TIFS, was used during the IFR portion of the evaluation task and drove the command bars on the ADI.

3.4 EVALUATION PROCEDURE AND TASK DESCRIPTION

The subject aircraft in these evaluations was a very large Class III military transport which was evaluated in the terminal area flight phase.

The evaluation tasks consisted of the following elements:

- Up-and-away airwork (Specific evaluations of up-and-away tasks were eliminated after the second evaluation flight to allow more time for approaches. Thereafter, the pilot was allowed to briefly sample the up-and-away characteristics of the configuration before the first approach and on the downwind leg between approaches.)
  - Trimmability
  - Maneuvering about level flight
  - Airspeed changes
  - Altitude changes
- Specific landing approaches aided by flight di- ctor information:
  - Localizer offset, randomly right or left.
  - Crosswind, randomly right or left.
  - Turbulence, α_g and β_g
  - Precise touchdown parameters

The approach and landing evaluation task, following the brief airwork, consisted of the following:

Precision tracking of the ILS beam, preceded by a "capture" segment beginning beyond the outer marker and at an angle between 30^{o} and 45^{o} to the beam. The evaluation pilot was "under a hood" during the simulated IFR approaches until the final portion starting from the middle marker at an altitude of approximately 300 feet down to the completion of the task. This latter portion of the approach including flare and a simulated touchdown at proper model eye height of 43 feet was to be completed visually. Precise simulated touchdowns were to be attempted. Acceptable landings were defined to be within a 1000 foot zone centered 1000 ft from the threshold of the runway, with a low sink rate (<5 ft/sec). Touchdown was signaled by a tone over the intercom and a signal light.

The task was made more difficult with the addition of localizer offsets and artificial or natural atmospheric disturbances of crosswinds and turbulence.

The localizer offset was a constant 1.5 degree or 1.2 dot angular offset that translated to a 400 ft lateral error at the breakout altitude of 300 feet. This forced the pilot to make lateral-directional corrections, so all of his attention was not kept on the longitudinal task.

The crosswind was added or canceled out with the TIFS sideslip mismatch capability. This capability is limited to a β of .1 radian, equivalent to a 15 knot change in the apparent crosswind at an airspeed of 150 knots.

Turbulence was also added to disturb the model's response. It was desired to have a light to moderate level of turbulence during each evaluation. When the natural level of turbulence was at this level, it was measured and introduced into the model's aerodynamic equations through α_g and β_g components added to the inertial α_I and β_I signals to form the total signals α_T and β_T. When the natural level of turbulence was less than this, artificially generated turbulence was introduced into the model. The turbulence signals recorded on an FM recorder are filtered Gaussian white noise. The filtered noise approximates a Dryden model of turbulence at one specific

altitude and speed. The filter characteristics were chosen to duplicate the power spectrum of turbulence at 330 feet and 150 KIAS. The α or vertical turbulence had a break frequency of .75 rad/sec (.12 Hz) and the β or lateral turbulence had a break frequency of .25 rad/sec (.04 Hz). The power spectral density plots for these turbulence signals are presented in Figures 11 and 12. The standard deviations of the artificial turbulence components were set at the following values to simulate moderate turbulence:

$$\sigma_{\alpha_g} = 1.13 \text{ deg } (5 \text{ ft/sec})$$

$$\sigma_{\beta_g} = 2.0 \text{ deg } (8.7 \text{ ft/sec})$$

Usually three approaches were flown for each evaluation of a configuration. The first was a long ILS approach as previously described. The 400 foot localizer offset was inserted. Crosswinds were canceled to let the pilot concentrate on the longitudinal control in flare and touchdown. The second and third approaches were usually visual, starting from an altitude of approximately 1000 feet above the ground on the downwind leg. The second approach had no localizer offset but had the 15-knot crosswind inserted. The third approach had both localizer offset (if it was an ILS) and the 15-knot crosswind inserted. All approaches had turbulence added to approximate a moderate level of intensity. The localizer offset and crosswinds were randomly alternated left or right. The evaluation pilot was allowed to choose a fourth approach at his discretion.

3.5 PILOTS AND EVALUATION SUMMARY

Two evaluation pilots participated in this flying qualities investigation. Both of them are Calspan Research Pilots with very extensive experience as flying qualities evaluation pilots. They are also flying qualities instructors at the Air Force and Navy Test Pilot Schools, demonstrating stability and control characteristics with Calspan's variable stability aircraft. Pilot A's flight experience of 7500 hours includes 750 hours in Class III aircraft. He was also an evaluation pilot in Calspan's space shuttle orbiter simulations. Pilot B's flight experience of 5500 hours has been in a wide variety of aircraft.

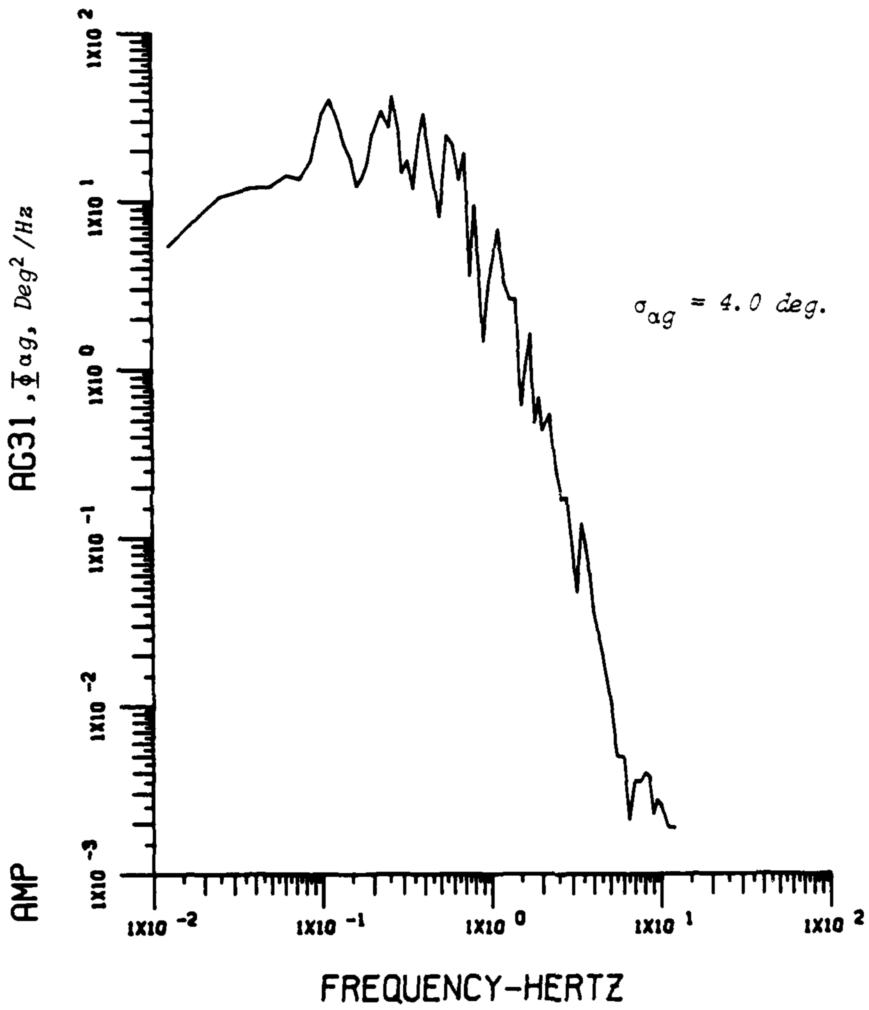


Figure 11. POWER SPECTRAL DENSITY OF VERTICAL TURBULENCE, αg

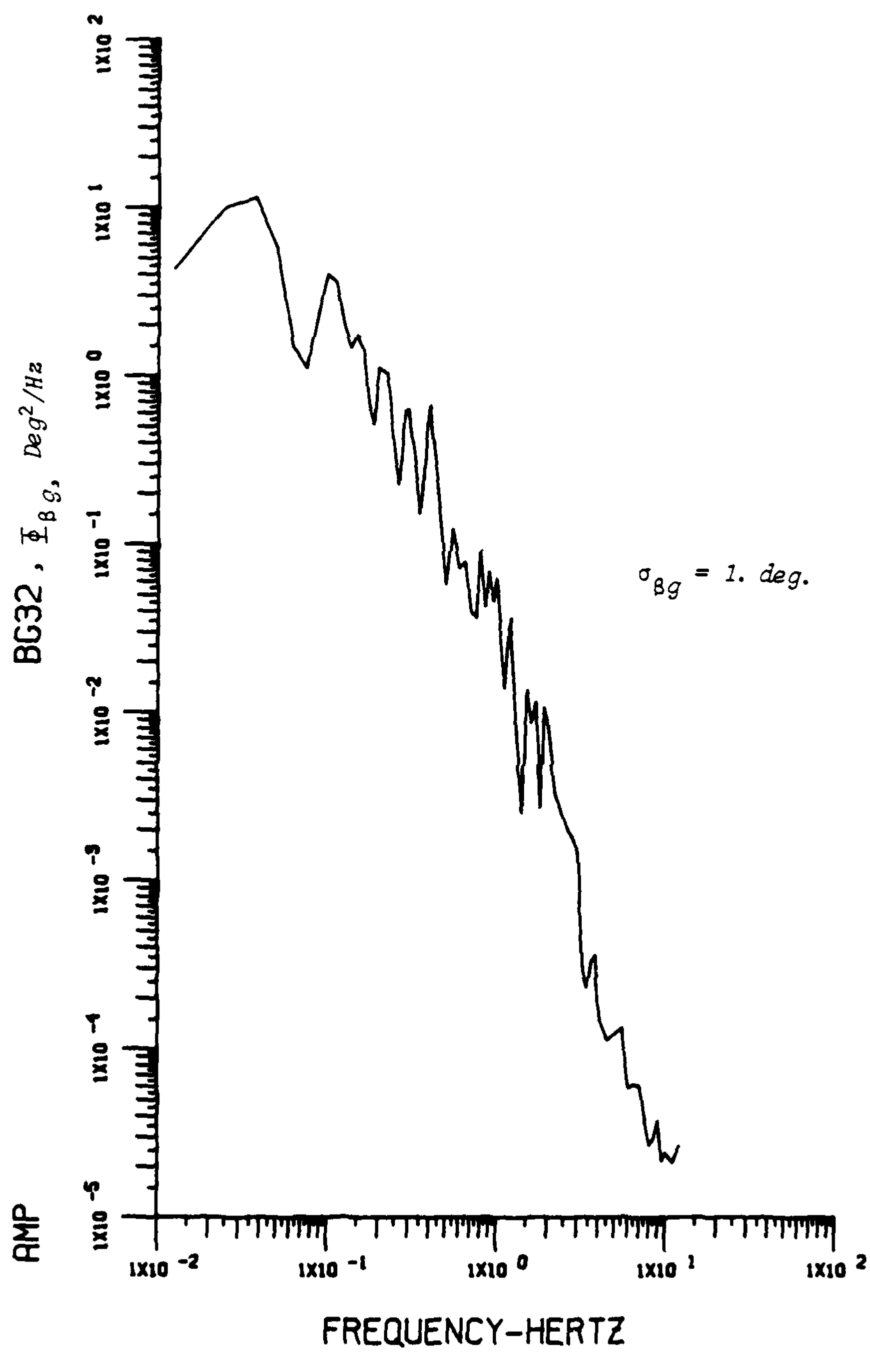


Figure 12. POWER SPECTRAL DENSITY OF LATERAL TURBULENCE, βg

The two pilots performed a total of 90 evaluations of 55 different configurations during the evaluation phase of the flight program. A total of 260 approaches were made. Twenty-four flights of approximately two hours each were flown. The distribution of flights and evaluations between the pilots was as follows:

	Pilot A	Pilot B
Flights	18	6
Evaluations	62	28
Configurations	53	25
Approaches	186	74

3.6 PILOT COMMENT CARD AND RATING SCALES

The evaluation pilots were briefed on the general experiment purposes and evaluation procedures before they flew. They were informed as to whether longitudinal or lateral-directional handling qualities were the prime subject of an individual evaluation. In addition, they were told which of the basic aircraft configurations (Long Aft Tail, Canard, Short Aft Tail) they were flying. It was believed that their control technique might have had to be changed for each one, and that they should know their location with respect to the main landing gear.

The pilots were asked to make brief comments on the configuration after each approach as the safety pilots were setting up the TIFS for the next approach. These comments were informal and covered initial impressions. After all of the approaches for an evaluation were completed, the evaluation pilot made his formal comments and pilot ratings. His comments followed the Comment Card shown in Figure 13. If the configuration was a lateral-directional evaluation, he also gave comments on the points shown on the B section of the Comment Card. After the formal comments, the pilot gave one Cooper-Harper rating (Figure 14) that covered all flying qualities in the landing approach task. In addition, a Pilot-Induced Oscillation (PIO) tendency classification (Figure 15) was given. This scale is a refinement of scales used in past Calspan evaluations.

A. LONGITUDINAL CONFIGURATIONS

1. Feel

   - forces, displacements?
   - pitch sensitivity? - trim?

2. Pitch attitude response to inputs required to perform task

   - initial response
   - predictability of final response
   - special pilot inputs?
   - tendency towards PIO?

3. Airspeed control

4. Approach performance

   - ILS: glideslope, localizer, throttle
   - visual approaches (sidestep maneuver)

5. Flare and touchdown performance

   - problems? - any special control techniques?

6. Differences between approach and landing tasks

   - significant? - most difficult task?

7. Effects of turbulence/wind

8. Lateral-directional characteristics: a factor in evaluation?

9. Summary (brief)

   - major problems - good features

10. Cooper-Harper Pilot Rating (separate ratings for different tasks if possible) - PIO rating.

B. LATERAL-DIRECTIONAL CONFIGURATIONS

1. Roll control authority
2. Roll control sensitivity
3. Roll response in general
4. Roll tendency to overshoot
5. Heading response

   a. turn entry
   b. roll out of turn

6. Tendency to sideslip for roll maneuvers
7. Rudder control

   a. power
   b. sensitivity

8. Tendency of A/C to maintain bank angle
9. Roll-pitch control harmony
10. Other comments – ride quality
    – initial accelerations vs. steady state
    – turbulence effects on ride quality
    – magnitude of inputs before accelerations become unsatisfactory or unacceptable

Figure 13. PILOT COMMENT CARD, APPROACH AND LANDING

HANDLING QUALITIES RATING SCALE

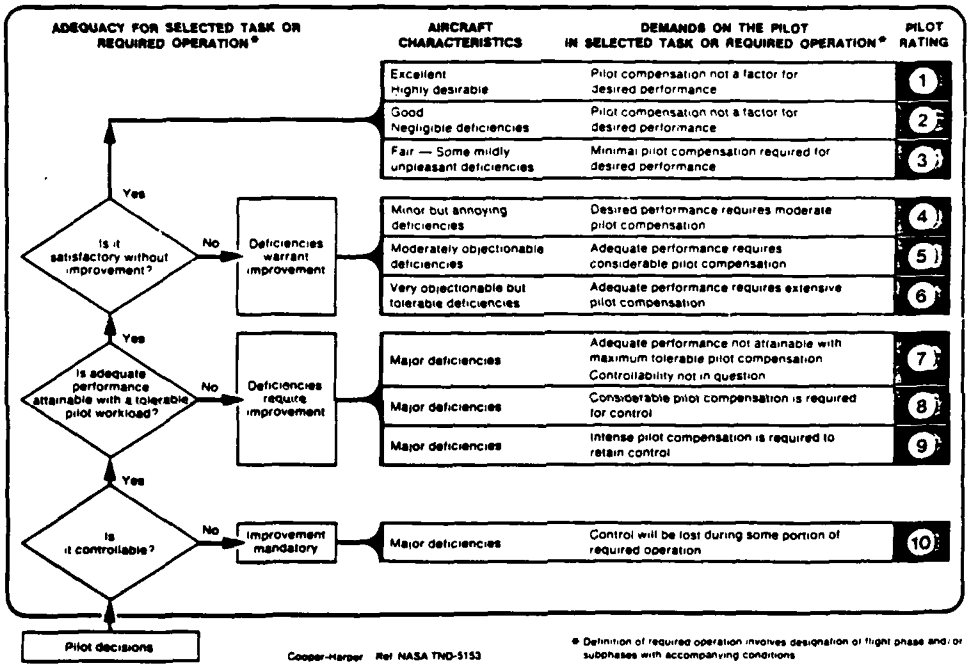


Figure 14. COOPER-HARPER HANDLING QUALITIES RATING SCALE

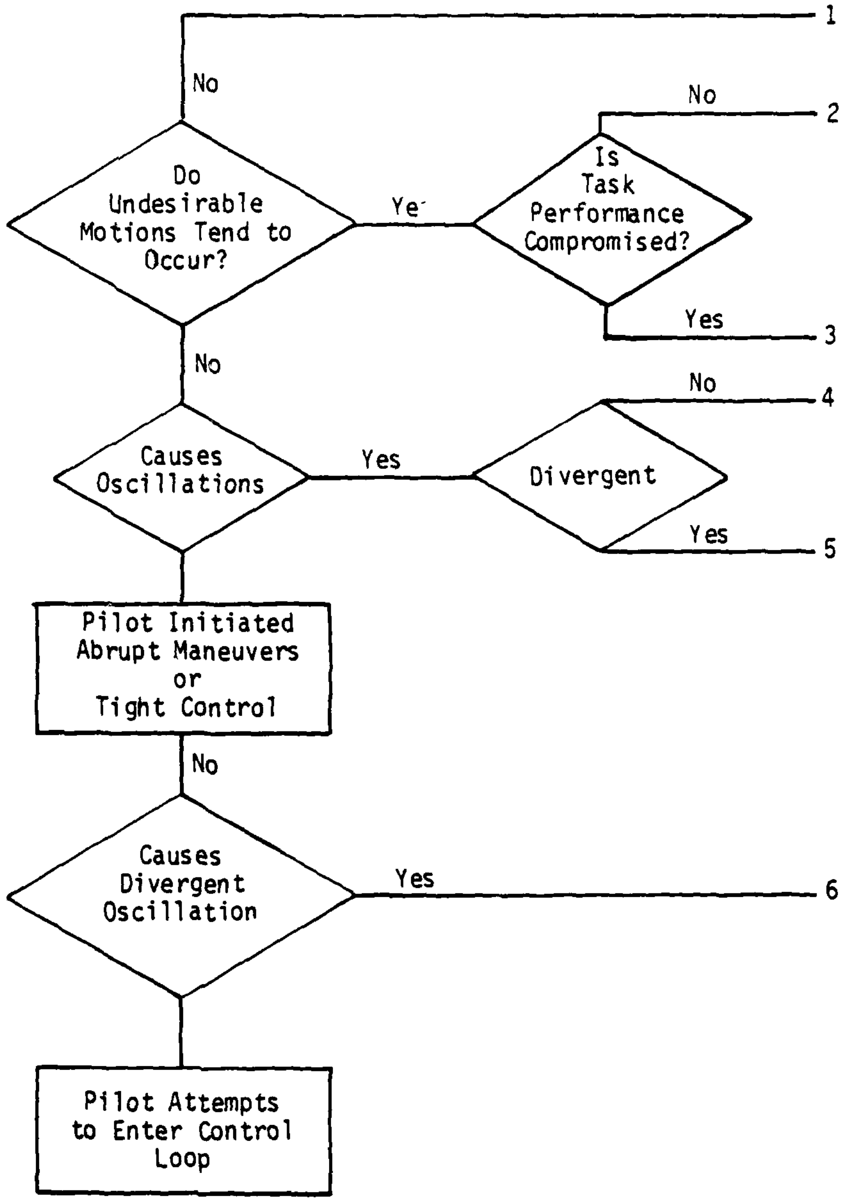


Figure 15. PIO TENDENCY CLASSIFICATION

Pilot commentary and ratings were recorded on a tape recorder in flight. These comments were transcribed and are available from Calspan files. Summaries are presented in Appendix III.

3.7 DATA RECORDING

A 58-channel digital recorder was used to record signals of interest. These included:

1. Pilot command inputs
2. Control surface motions
3. Aircraft states — model and TIFS
4. Localizer and glideslope deviation
5. Radar altitude
6. Turbulence inputs

The crew members estimated the position of the touchdown point on the runway. A specific list of recorded variables is presented in Appendix VII.

3.8 MODEL-FOLLOWING VERIFICATION

Samples of model-following responses are shown for two configurations in Figures 16 through 19. These include pitch and roll automatic steps and typical approach records. The .06 sec and .12 sec model-following delay in pitch rate and roll rate, respectively, can be seen. Figure 18 shows a PIO developing with the Short Aft Tail configuration. Most of the higher-frequency differences between the model and TIFS responses are due to natural turbulence which was not inserted into the model on these records. There were some errors in angle of attack model-following, especially in turns, which were later traced to air data computational errors in the TIFS sensor system. However, these problems did not affect the model following of the primary variables of pitch rate and normal acceleration. Early in the evaluation program, due to the sensor problem, the model was given an erroneous low dynamic pressure at the system engage point. This forced the model to trim at a slightly higher angle of attack than desired. This would put the model further aft on the backside of its power-required curve. On a few approaches, this complicated the

airspeed control task, which was already difficult due to slow model thrust response. The evaluation pilots noted the approaches on which they had these extra airspeed control problems and attempted to ignore these effects when rating the configurations. Specifically, on flights 610 through 616, there were sensor errors which forced the higher than normal trim angle of attack. Also on flights 619 through 623 the sensed dynamic pressure for the TIFS was used in calculating the dynamic pressure of the model. This allowed, natural turbulence and actual windshear effects on velocity disturb the model's aerodynamics. Airspeed problems on all other flights were taken into account in the pilot ratings.

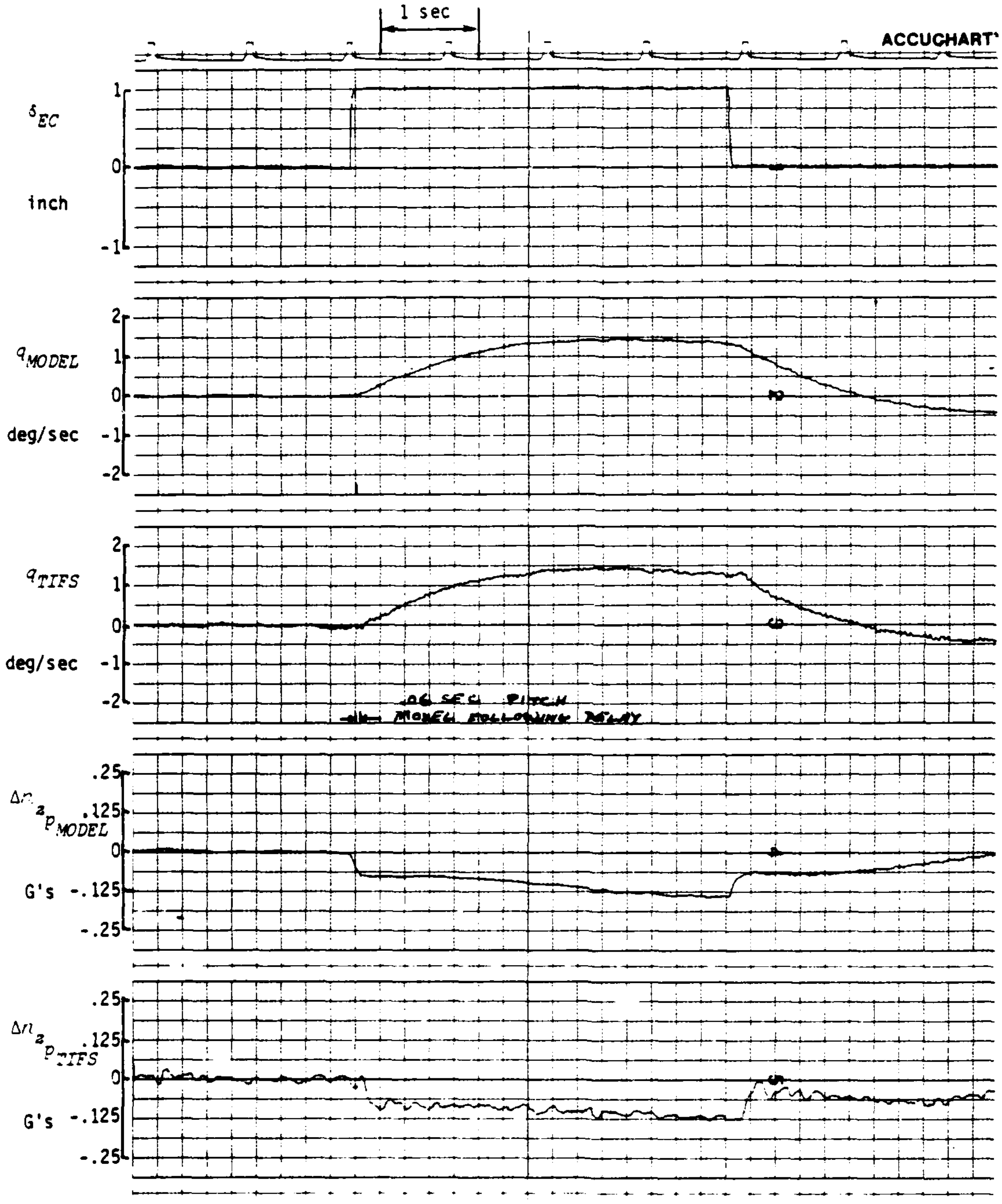


Figure 16. MODEL FOLLOWING - PITCH STEP CANARD, HIGH α, T_1 = A, FLT 604, REC 27

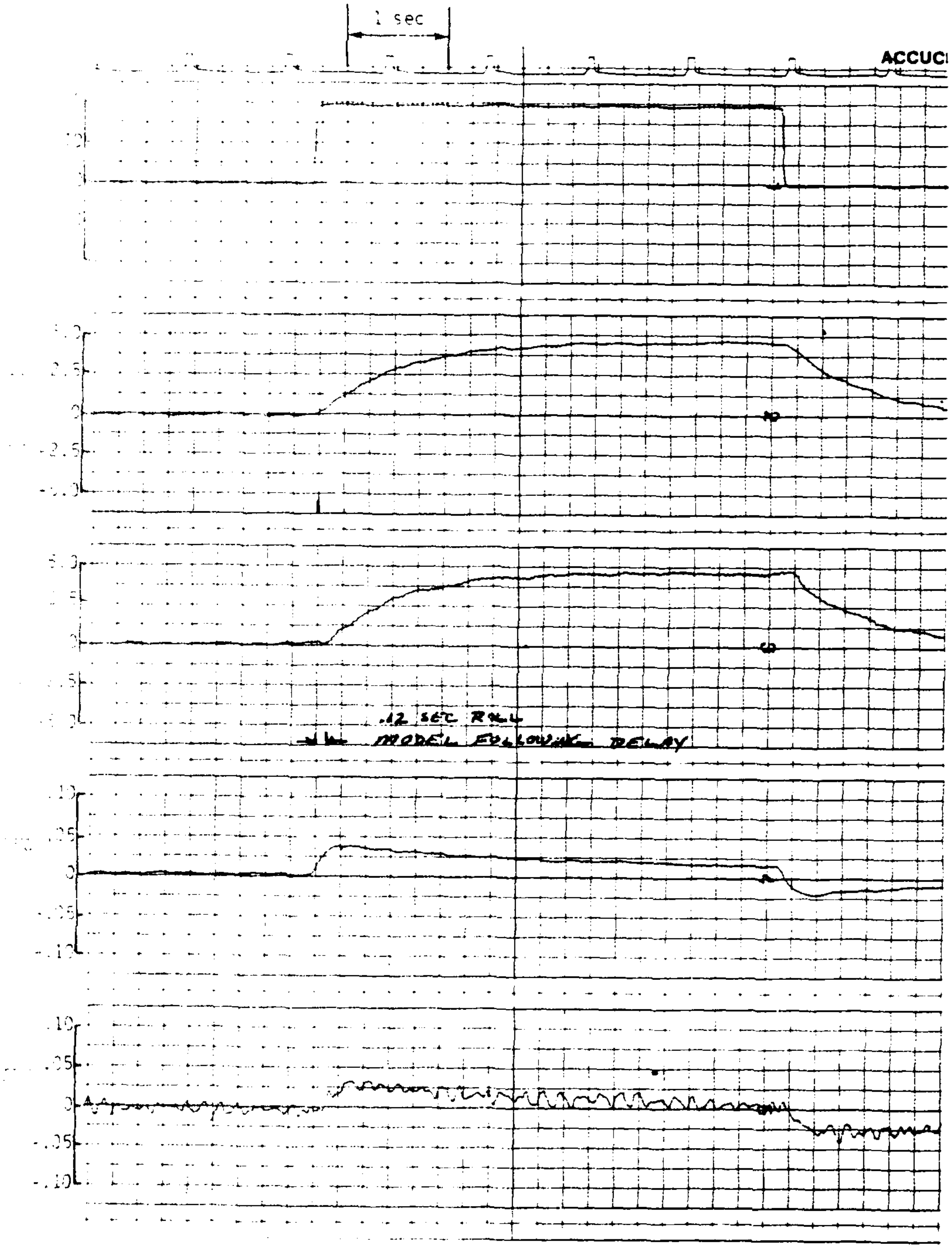


Figure 17. MODEL FOLLOWING ROLL STEP τ_R = .87,
C_{OF} = 18 FT, T_1 = A, FLT 604, REC 28

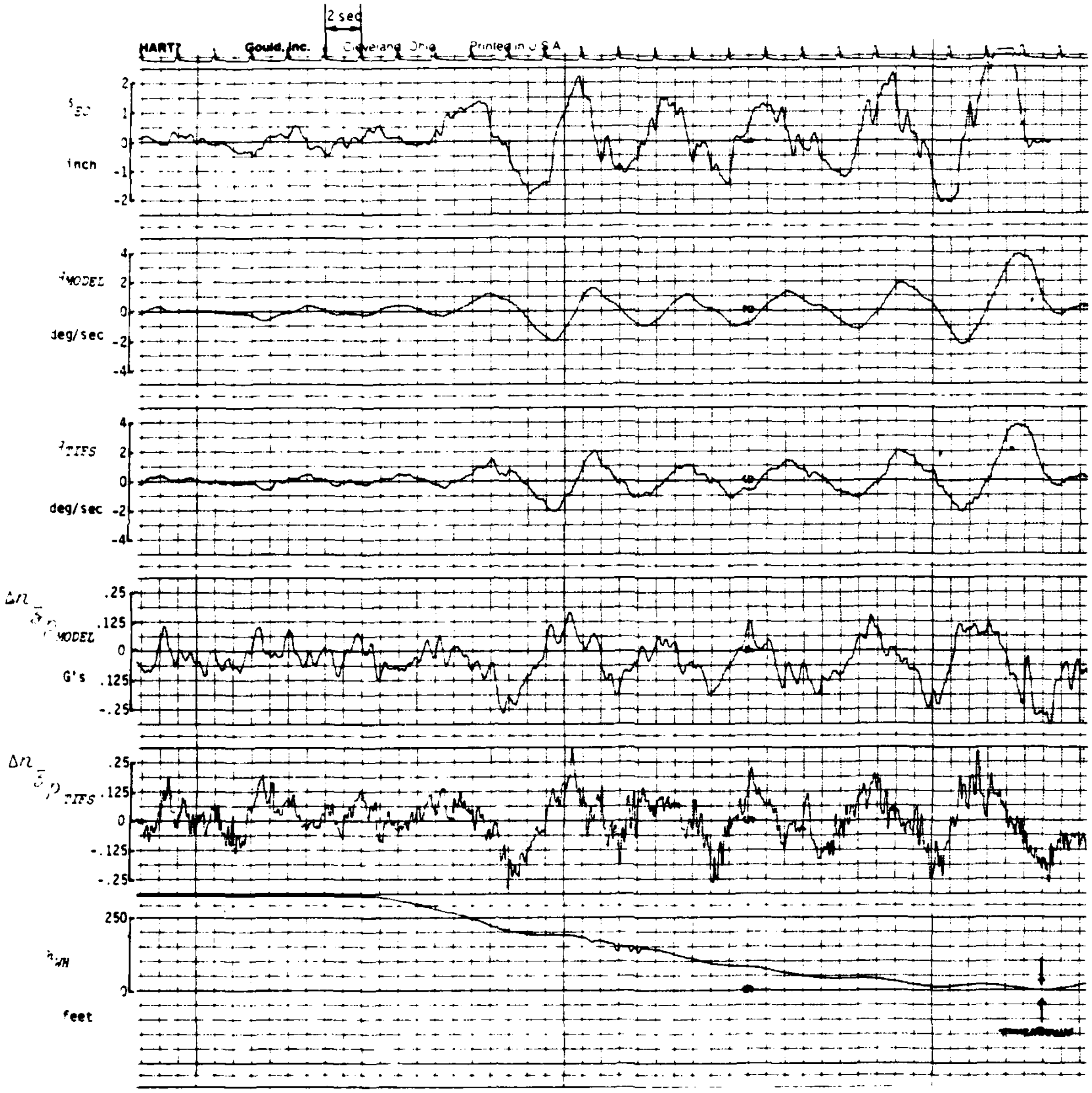


Figure 18. MODEL FOLLOWING - LONGITUDINAL ON APPROACH (INCLUDES PIO) SHORT AFT TAIL, MED α, T_1 = B, FLT 615, REC 31

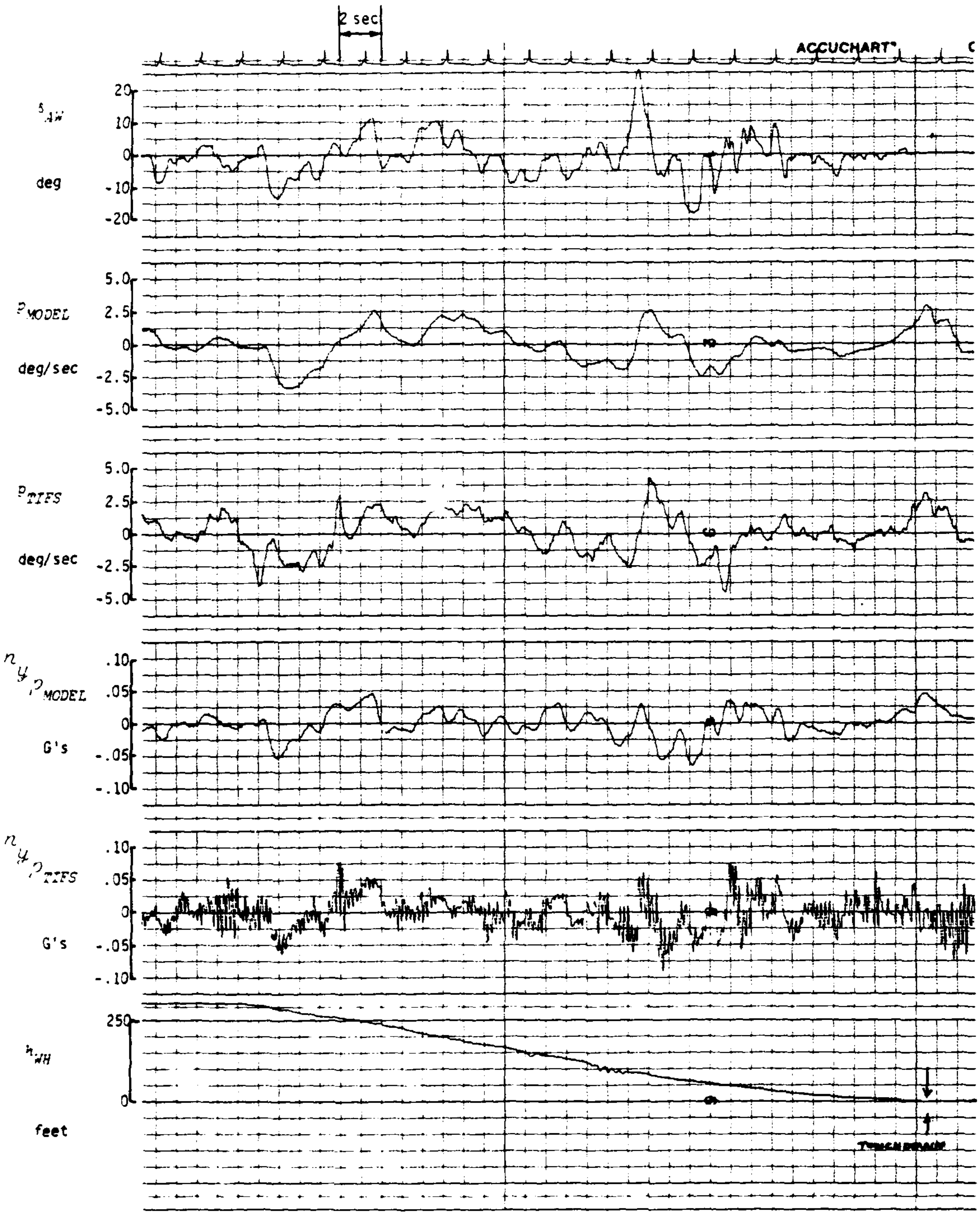


Figure 19. MODEL FOLLOWING - LATERAL/DIRECTIONAL ON APPROACH, τ_R = .87, Z_{SP} = -18 FT, FLT 615, REC 10

Section 4
EXPERIMENT RESULTS AND ANALYSIS

4.1 INTRODUCTION

The results of the Large Airplane flying qualities experiment are presented in this section. The data obtained from the experiment are in the form of pilot ratings and pilot comments. Correlations of pilot rating with the various experimental variables are presented. Pitch attitude, pilot/aircraft control-loop analysis was performed to correlate with the data. A multi-loop analysis of pitch attitude and altitude control is also presented. Finally, a discussion of the turbulence response is given.

The pilot comment summaries from the evaluated configurations were too lengthy to include in this section and are presented in Appendix III. The Appendices also contain additional data correlations and analyses which were carried out. These include equivalent system analysis in Appendix V-A, time history criteria for pitch rate response in Appendix V-B, and open-loop aircraft and aircraft plus uncompensated pilot analysis in Appendix V-C and V-D.

As an aid in following the analysis in this section, a Configuration-Flight Index, along with a Chronological Flight/Configuration Log (Tables IV and V) are presented. This will allow one to determine the flight on which a specific configuration was flown, the pilot, the order of configurations flown, the number of approaches, pilot ratings, and any special remarks for that configuration presentation. In addition, Tables VI and VII present a listing of the pilot ratings and PIO ratings in a summary form.

TABLE IV

CONFIGURATION - FLIGHT INDEX

Configuration (All longitudinal config's flown with $\tau_R = .37$ sec, $Z_{sp} = -15'$, $T_{1_{roll}} = A$)		Flight/Pilot Level of Delay (T_1) A	B	C
<u>Long Aft Tail</u>	Unaugmented	611/A		610/A
	Low α gain	611/A	609/A	608/A,614/B
	Med α	609/A	608/A,614/B	610/A
	High α	608/A,613/A, 618/A	610/A,626/A	609/A,614/B
	Ex-High α	629/A		
	High α, $N_z/\alpha = 3$	615/B,618/A		
	High α, $N_z/\alpha = 2$	615/B,618/A		
	Low q gain	617/A,626/A		611/A,613/B
	Med q	612/A	612/A,613/B	612/A
	High q	611/A,613/B, 615/B,623/A	613/B,617/A	612/A
	High q ($X_{mp} = 50'$)	627/A,631/B		
<u>Canard</u>	Unaugmented	627/A		
	Low α gain	622/A	621/A	616/B,616/B, 620/A
	Med α	621/A	616/B,620/A	622/A
	High α	616/B,620/A, 621/A,622/A	622/A	616/B,621/A
	Ex-High α	630/A		
	High q gain	627/A		
	High q ($X_{mp} = 50'$)	627/A		

TABLE IV (CONT'D)

CONFIGURATION - FLIGHT INDEX

Configuration (All longitudinal config's flown with $\tau_R = .87_{sec}$, $Z_{sp} = -18'$, $T_{1_{roll}} = A$)		Flight/Pilot Level of Delay (T_1) A	B	C
Short Aft Tail	Med α gain	619/A	615/B,618/A	
	High α	615/B,618/A 630/A with DLC 630/A	619/A	
	Med q gain	619/A		
	High q	615/B,619/A 630/A,631/B, with DLC 629/A		631/B (T_1=.35)
	High q (X_{mp} = 70')	629/A,631/B		
	High q (X_{mp} = 110')	629/A,631/B		
	Ex-High q	631/B		
Lat-Directional (All with long aft, high q, $T_{1_{pitch}} = A$)	$\tau_R = .87$, Z_{sp}=-18'	611/A,613/B, 615/B,623/A,	624/A	626/A
	τ_R =.44, Z_{sp} = -18'	623/A, 625/B	626/A	624/A,627/A
	τ_R = .87, Z_{sp}= -36'	623/A, 625/B		
	τ_R = .44, Z_{sp}= -36'	623/A, 625/B		

TABLE V

CHRONOLOGICAL FLIGHT/CONFIGURATION LOG

FLT	1980 DATE	CONFIGURATION, GAIN, DELAY	PILOT	PR	PIOR	APPROACHES	OTHER REMARKS
							All at Niagara and nominal gearings except as noted.
608	7/25	Long aft, high α, $T_1 = A$	A	5	2	1-ILS, 2-VIS	
		Long aft, med α, $T_1 = B$	A	7	3	1-ILS, 2-VIS	
		Long aft, low α, $T_1 = C$	A	9	4	1-ILS, 1-VIS	
609	7/25	Long aft, high α, $T_1 = C$	A	6	3	1-ILS, 2-VIS	7-1/2 lb/in gradient on third app.
		Long aft, med α, $T_1 = A$	A	6	3	2-ILS, 3-VIS	
		Long aft, low α, $T_1 = B$	A	9	--	1-ILS	
610	7/29	Long aft, high α, $T_1 = B$	A	7	4	1-ILS, 2-VIS	
		Long aft, unaug, $T_1 = C$	A	10	4	1-ILS, 2-VIS	
		Long aft, med α, $T_1 = C$	A	8	4	1-ILS, 3-VIS	
611	7/29	Long aft, low α, $T_1 = A$	A	5	1	1-ILS, 2-VIS	App's at Buffalo.
		Long aft, unaug, $T_1 = A$	A	6	2	1-ILS, 2-VIS	App's at Buffalo.
		Long aft, high q, $T_1 = A$	A	3	1	1-ILS, 2-VIS	App's at Buffalo.
		Long aft, low q, $T_1 = C$	A	10	5	2-ILS	1 app at Buffalo, 1 app at Niagara.
612	7/30	Long aft, med q, $T_1 = B$	A	5	3	1-ILS, 2-VIS	
		Long aft, high q, $T_1 = C$	A	5	4	2-ILS, 1-VIS	
		Long aft, med q, $T_1 = A$	A	4-1/2	3	1-ILS, 2-VIS	
		Long aft, med q, $T_1 = C$	A	6	4	1-ILS, 1-VIS	
613	7/30	Long aft, high q, $T_1 = A$	B	4	3	2-ILS, 2-VIS	1st eval. for Pilot B.
		Long aft, low q, $T_1 = C$	B	9	5	1-ILS, 1-VIS	

TABLE V (CONT'D)

CHRONOLOGICAL FLIGHT/CONFIGURATION LOG

FLT	1980 DATE	CONFIGURATION, GAIN, DELAY	PILOT	PR	PIOR	APPROACHES	OTHER REMARKS
							All at Niagara and nominal gearings except as noted.
613 cont.	7/30	Long aft, med q, $T_1 = B$	B	7	4	1-ILS,2-VIS	
		Long aft, high q, $T_1 = B$	B	2	1	1-ILS,1-VIS	
		Long aft, high α, $T_1 = A$	B	2	1	1-ILS,2-VIS	
614	7/31	Long aft, med α, $T_1 = B$	B	5	1	1-ILS,2-VIS	
		Long aft, low α, $T_1 = C$	B	7	4	1-ILS,1-VIS	
		Long aft, high α, $T_1 = C$	B	7	3	1-ILS,2-VIS	From this config. on, Pilot B flew with 15 rad/sec pitch feel system.
		Long aft, $N_z/\alpha=3$, $T_1 = A$	B	4-1/2	1	1-ILS,3-VIS	
615	7/31	Long aft, $N_z/\alpha=2$, $T_1 = A$	B	5-1/2	1	1-ILS,2-VIS	
		Long aft, high q, $T_1 = A$	B	1	1	1-ILS,1-VIS	
		Short aft, high α, $T_1 = A$	B	10	4	1-ILS,3-VIS	
		Short aft, med α,$T_1 = B$	B	10	6	1-ILS,1-VIS	
		Short aft, high q, $T_1 = A$	B	6	3	1-ILS,1-VIS	
616	8/1	Canard, low α, $T_1 = C$	B	4-1/2	1	2-ILS,1-VIS	1.3 x nominal gearing.
		Canard, med α, $T_1 = B$	B	5	1	1-ILS,1-VIS	
		Canard, high α, $T_1 = A$	B	3	1	1-ILS,1-VIS	
		Canard, high α, $T_1 = C$	B	5	1	1-ILS,1-VIS	
		Canard, low α, $T_1 = C$	B	6	3	1-ILS,1-VIS	
617	8/1	Long aft, high q, $T_1 = B$	A	3	1	1-ILS,2-VIS	

TABLE V (CONT'D)

CHRONOLOGICAL FLIGHT/CONFIGURATION LOG

FLT	1980 DATE	CONFIGURATION, GAIN, DELAY	PILOT	PR	PIOR	APPROACHES	OTHER REMARKS
							All at Niagara and nominal gearings except as noted.
617	8/1	Long aft, low q, $T_1 = A$	A	10	5	1-ILS,1-VIS	Cut off flt. due to poor weather.
618	8/4	Long aft, $N_z/\alpha=3$, $T_1 = A$	A	6	3	1-ILS,2-VIS	
		Long aft, $N_z/\alpha=2$, $T_1 = A$	A	7	4	1-ILS,3-VIS	1.3 x nominal gearing.
		Long aft, high α, $T_1 = A$	A	6	3	1-ILS,2-VIS	
		Short aft, high α, $T_1 = A$	A	9	5	1-ILS,2-VIS	1.3 x nominal gearing.
		Short aft, med α, $T_1 = B$	A	10	5	1-ILS,1-VIS	1.3 x nominal gearing.
619	8/4	Short aft, high α, $T_1 = B$	A	10	6	1-ILS,2-VIS	2.0 x nominal gearing.
		Short aft, med α, $T_1 = A$	A	10	5	1-ILS,2-VIS	No G/S guidance.
		Short aft, med q, $T_1 = A$	A	9	4	1-ILS,2-VIS	2 x nominal gearing, at Rochester.
		Short aft, high q, $T_1 = A$	A	9	4	1-ILS,2-VIS	at Rochester
620	8/5	Canard, high α, $T_1 = A$	A	4	1	2-ILS,1-VIS	
		Canard, low α, $T_1 = C$	A	6	3	1-ILS,2-VIS	
		Canard, med α, $T_1 = B$	A	5	3	1-ILS,3-VIS	
621	8/5	Canard, high α, $T_1 = C$	A	5	3	1-ILS,2-VIS	1.3 x nominal gearing.
		Canard, med α, $T_1 = A$	A	4-1/2	1	1-ILS,2-VIS	
		Canard, low α, $T_1 = B$	A	6	3	1-ILS,2-VIS	
		Canard, high α, $T_1 = A$	A	6	3	1-ILS,2-VIS	1.3 x nominal gearing.
622	8/6	Canard, high α, $T_1 = A$	A	4	2	1-ILS,2-VIS	
		Canard, med α, $T_1 = C$	A	6	4	1-ILS,2-VIS	

TABLE V (CONT'D)

CHRONOLOGICAL FLIGHT/CONFIGURATION LOG

FLT	1980 DATE	CONFIGURATION, GAIN, DELAY	PILOT	PR	PIOR	APPROACHES	OTHER REMARKS
							All at Niagara and nominal gearings except as noted.
622 cont.	8/6	Canard, high α, $T_1 = B$	A	5	3	1-ILS,3-VIS	
		Canard, low α, $T_1 = A$	A	3	2	1-ILS,1-VIS	
623	8/6	Lat-Dir, τ_R=.87, Z=-36, T_1=A	A	4	2	1-ILS,2-VIS	at Rochester.
		Lat-Dir, τ_R=.44, Z=-18, T_1=A	A	3	2	1-ILS,2-VIS	at Rochester.
		Lat-Dir, τ_R=.44, Z=-36, T_1=A	A	5	3	2-ILS,1-VIS	at Rochester.
		Lat-Dir, τ_R=.87, Z=-18, T_1=A	A	4-1/2	2	1-ILS,2-VIS	at Rochester, same configuration as long aft, high q.
624	8/8	Lat-Dir, τ_R=.87, Z=-18, T_1=B	A	4-1/2	3	1-ILS,2-VIS	
		Lat-Dir, τ_R=.44, Z=-18, T_1=C	A	3	2	1-ILS,2-VIS	
625		Lat-Dir, τ_R=.87, Z=-36, T_1=A	B	4	1	1-ILS,2-VIS	
		Lat-Dir, τ_R=.44, Z=-18, T_1=A	B	2	1	1-ILS,1-VIS	1 app. at Niagara, 1 app. at Buffalo.
		Lat-Dir, τ_R=.44, Z=-36, T_1=A	B	5-1/2	1	1-ILS,2-VIS	at Buffalo.
626	8/11	Lat-Dir, τ_R=.87, Z=-18, T_1=C	A	5	2	2-ILS,1-VIS	
		Lat-Dir, τ_R=.44, Z=-18, T_1=B	A	4	1	1-ILS,2-VIS	
		Long aft, low q, $T_1 = A$	A	8	4	1-ILS,2-VIS	1.5 x nominal gearing.
		Long aft, high α, $T_1 = B$	A	6	3	1-ILS,1-VIS	1.3 x nominal gearing.
627	8/11	Canard, High q, T_1=A, X_p=50'	A	3	1	1-ILS,2-VIS	1.5 x nominal gearing.
		Canard, High q, $T_1 = A$	A	3	1	1-ILS,2-VIS	Same PR, but felt better than [illegible].

TABLE V (CONT'D)

CHRONOLOGICAL FLIGHT/CONFIGURATION LOG

FLT	1980 DATE	CONFIGURATION, GAIN, DELAY	PILOT	PR	PIOR	APPROACHES	OTHER REMARKS
							All at Niagara and nominal gearings except as noted.
627 cont.	8/11	Canard, unaug., $T_1 = A$	A	8	4	1-ILS,2-VIS	1.3 x nominal gearing.
		Long aft, high q, T_1=A, X_p=$50'$	A	2-1/2	1	1-ILS,2-VIS	
		Lat-Dir, τ_R=.44, Z=-18, T_1=C	A	3	2	1-ILS,1-VIS	
629	8/12	Short aft, high q, T_1=A,X_p=$70'$	A	5	1	1-ILS,2-VIS	at Buffalo.
		Short aft, high q, T_1=A,X_p=$110'$	A	4-1/2	1	1-ILS,3-VIS	at Buffalo.
		Short aft, high q, T_1=A, DLC	A	5	2	1-ILS,4-VIS	
		Long aft, Ex-Hi α, $T_1 = A$	A	5	2	1-ILS,2-VIS	at Buffalo.
630	8/13	Short aft, high q, $T_1 = A$	A	5	3	1-ILS,2-VIS	1.5 x nominal gearing.
		Short aft, high α, $T_1 = A$	A	8	4	1-ILS,2-VIS	1.3 x nominal gearing.
		Short aft, high α, T_1=A, DLC	A	6	3	1-ILS,3-VIS	1.3 x nominal gearing.
		Canard, Ex-Hi α, T_1=A	A	5	2	1-ILS,2-VIS	
631	8/14	Short aft, high q, T_1=A,X_p=$70'$	B	8	3	1-ILS,2-VIS	
		Short aft, high q, $T_1 = .35$	B	9	4	1-ILS,2-VIS	Equivalent shuttle delay/lag
		Short aft, Ex-Hi q, $T_1 = A$	B	4	2	1-ILS,1-VIS	
		Short aft, high q, T_1=A,X_p=$110'$	B	3	1	1-ILS,2-VIS	
		Short aft, high q, $T_1 = A$	B	4	2	1-ILS,1-VIS	at Buffalo, 1.5 x nominal gearing.
		Long aft, high q, T_1=A,X_p=$50'$	B	2	1	1-ILS,1-VIS	at Buffalo, 1.5 x nominal gearing.

TABLE VI

COOPER-HARPER PILOT RATINGS (PR)

CONFIGURATION (All longitudinal config's flown with $\tau_R = .87$ sec, $Z_{sp} = -18'$, $T_{1_{roll}} = A$)		LEVEL OF DELAY (T_1) A		B		C	
		Pilot A	Pilot B	Pilot A	Pilot B	Pilot A	Pilot B
Long Aft $X_{mp}=110'$ $X_{PCR}=92.5'$	Unaug.	6				10	
	Low α gain	5		9		9	7✓
	Med α	6		7	5✓	8	
	High α	5,6	2✓	7,6		6	7
	Ex-Hi α	5					
	Hi-α, $N_z/\alpha=3$	6	4-1/2				
	Hi-α, $N_z/\alpha=2$	7	5-1/2				
	Low q gain	10,8				10	9✓
	Med q	4-1/2		5	7✓	6	
	High q	3,4-1/2	4 (1st eval) 1	3	2✓	5	
	High ($X_{mp}=50'$, $X_{PCR}=32.5$)	2-1/2	2				
Canard $X_{mp}=110'$ $X_{PCR}=140'$	Unaug.	8					
	Low α gain	3		6		6	4-1/2,6
	Med α	4-1/2		5	5	6	
	High α	4,6, 4	3	5		5	5
	Ex-Hi α	5					
	High q gain	3					
	High q ($X_{mp}=50'$, $X_{PCR}=80'$)	3					

✓Pilot B longitudinal config's flown with feel system ω_n = 15 rad/sec, except those checked which were at 25 rad/sec. Pitch feel system ω_n = 25 rad/sec, for all Pilot A evaluations.

TABLE VI (CONT'D)

COOPER-HARPER PILOT RATINGS (PR)

CONFIGURATION (All longitudinal config's flown with $\tau_R = .87$ sec, $Z_{sp} = -18'$, $T_{1_{roll}} = A$)		LEVEL OF DELAY (T_1) A		B		C	
		Pilot A	Pilot B	Pilot A	Pilot B	Pilot A	Pilot B
Short Aft $X_{mp}=50'$ $X_{PCR}=-10'$	Med α gain	10 (DLC)		10	10		
	High α	9,8,6	10	10			
	Med q gain	9 (DLC)					
	High q	9,5,5	6,4				9 (T_1=.35)
	High $q\begin{pmatrix}X_{mp}=70'\\X_{PCR}=10'\end{pmatrix}$	5	8*				
	High $q\begin{pmatrix}X_{mp}=110'\\X_{PCR}=50'\end{pmatrix}$	4-1/2	3				
	Ex-Hi q		4				
Lat-Dir: All flown with long aft, high q gain $T_{1_{pitch}} = A$							
	$\tau_R = .87$ sec, $Z_{sp}=-18'$	3,4-1/2	4 (1st eval) 1	4-1/2		5	
	$\tau_R = .44$, $Z_{sp}=-18'$	3	2	4		3,3	
	$\tau_R = .87$, $Z_{sp}=-36'$	4	4				
	$\tau_R = .44$, $Z_{sp}=-36'$	5	5-1/2				

*First configuration flown after one week non-flying, said may have been biased against all short aft configurations at start of flight.

Pitch feel system: Pilot A ~ ω_n = 25 rad/sec
Pilot B ~ ω_n = 15 rad/sec

TABLE VII

PILOT-INDUCED OSCILLATION RATINGS (PIOR)

CONFIGURATION All longitudinal config's flown with $\tau_R = .87$ sec, $Z_{sp} = -18'$, $R_{T_{1_{roll}}} = A$)		LEVEL OF DELAY (T_1)					
		A		B		C	
		Pilot A	Pilot B	Pilot A	Pilot B	Pilot A	Pilot B
Long Aft Tail	Unaug.	2				4	
	Low α gain	1				4	4✓
	Med α	3		3	1✓	4	
	High α	2,3	1✓	4,3		3	3
	Ex-Hi α	2					
	Hi-α, $N_z/\alpha = 3$ g/rad	3	1				
	Hi-α, $N_z/\alpha = 2$	4	1				
	Low q gain	5,4				5	5✓
	Med q	3		3	4✓	4	
	High q	1,2	3(1st eval),1	1	1✓	4	
	High q (X_{mp}=50')	1	1				
Canard	Unaug.	4					
	Low α gain	2		3		3	1,3
	Med α	1		3	1	4	
	High α	1,3,2	1	3		3	1
	Ex-Hi α	2					
	High q gain	1					
	High q (X_{mp}=50')	1					

✓Pitch feel system: Pilot A - ω_n = 25 rad/sec
Pilot B - ω_n = 15 rad/sec, <u>except</u> those checked which were at 25 rad/sec.

TABLE VII (CONT'D)

PILOT-INDUCED OSCILLATION RATINGS (PIOR)

CONFIGURATION All longitudinal config's flown with τ_R = .87 sec, Z_{sp} = -18', $T_{1_{roll}}$ = A)		LEVEL OF DELAY (T_1)					
		A		B		C	
		Pilot A	Pilot B	Pilot A	Pilot B	Pilot A	Pilot B
Short Aft	Med α gain	5		5	6		
	High α	5,4,3 (DLC)	4	6			
	Med q gain	4					
	High q	4,3,2 (DLC)	3,2				4 (T_1=.35)
	High q (X_{mp}=70')	1	3*				
	High q (X_{mp}=110')	1	1				
	Ex-Hi q		2				
Lat-Dir (All with long aft High q $T_{1_{pitch}}$ = A)	τ_R=.87 sec, Z_{sp}=-18'	1,2	3 (1st eval), 1	3		2	
	τ_R=.44, Z_{sp}=-18'	2	1	1		2,2	
	τ_R=.87, Z_{sp}=-36'	2	1				
	τ_R=.44, Z_{sp}=-36'	3	1				

*First config. flown after one week non-flying, said may have been biased against all short aft config's at start of flight.

Pitch feel system: Pilot A ~ ω_n = 25 rad/sec
Pilot B ~ ω_n = 15 rad/sec

4.2 PILOT RATINGS VERSUS EXPERIMENT VARIABLES

The primary variables in the Large Airplane experiment were:

- Pilot location with respect to pitch center of rotation presented as three different aircraft design configurations — Long Aft Tail, Canard, and Short Aft Tail, plus other locations.

- Augmentation schemes — α-feedback and q-feedbcck with proportional plus integral command to yield attitude hold.

- Level of augmentation — from statically unstable to Level 1 stability.

- Time delay — produced by model following lags and inserted prefilters and pure time delays.

- Lateral acceleration due to roll inputs — varied by roll mode time constant, pilot vertical position with respect to stability axis, and prefilters and delays.

The effect of these parameter variations on pilot ratings are shown in Figures 20 through 31. The total effective time delay, t_1, was measured by the maximum slope intercept method from computed time histories. It includes the feel system, added lags or delays, model control system, airplane model, and TIFS model-following delay. Appendix V-B presents a tabulation of t_1 for the pitch configurations.

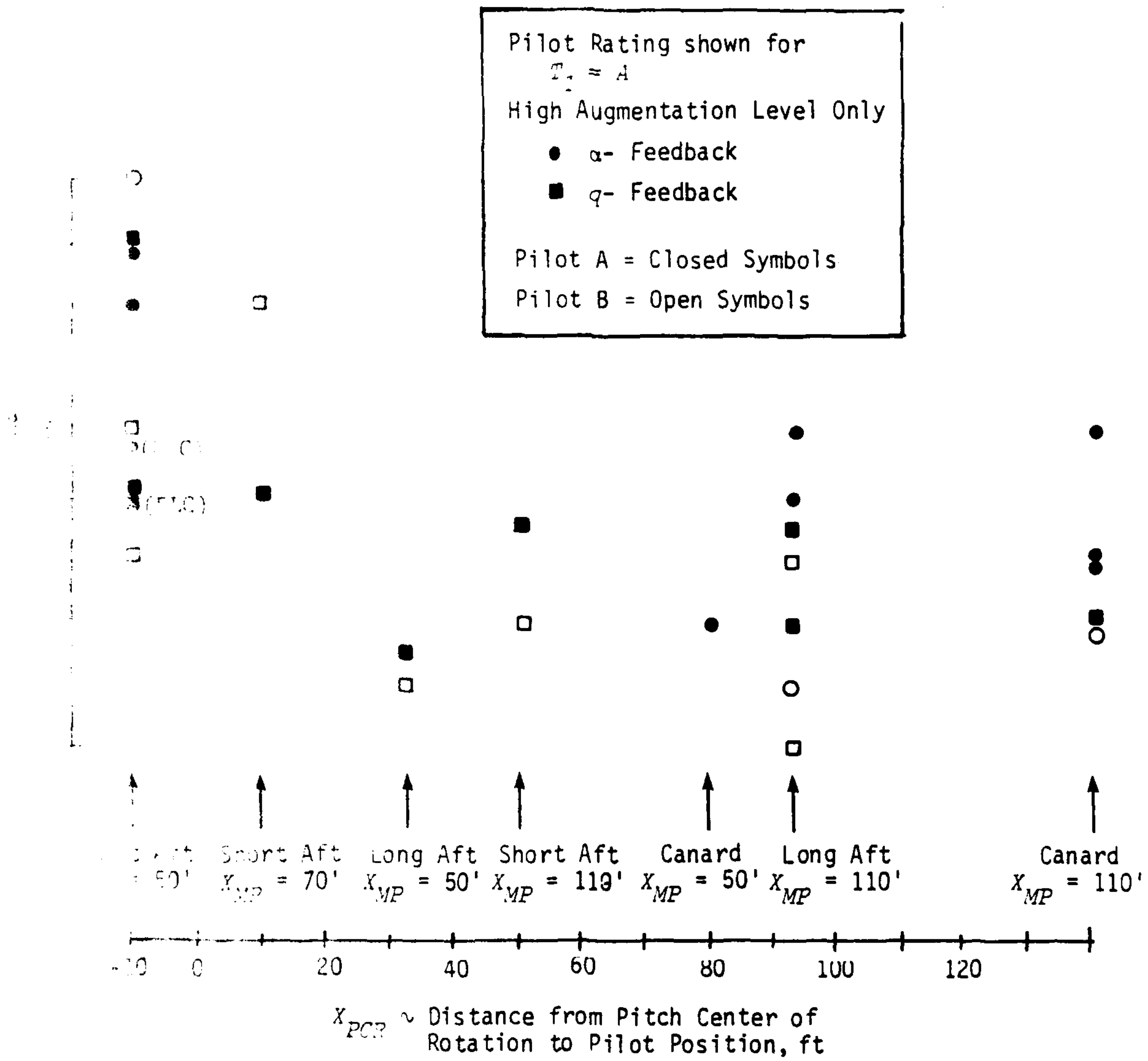


Figure 20. PILOT RATING VS PILOT POSITION - CENTER OF ROTATION (X_{PCR})

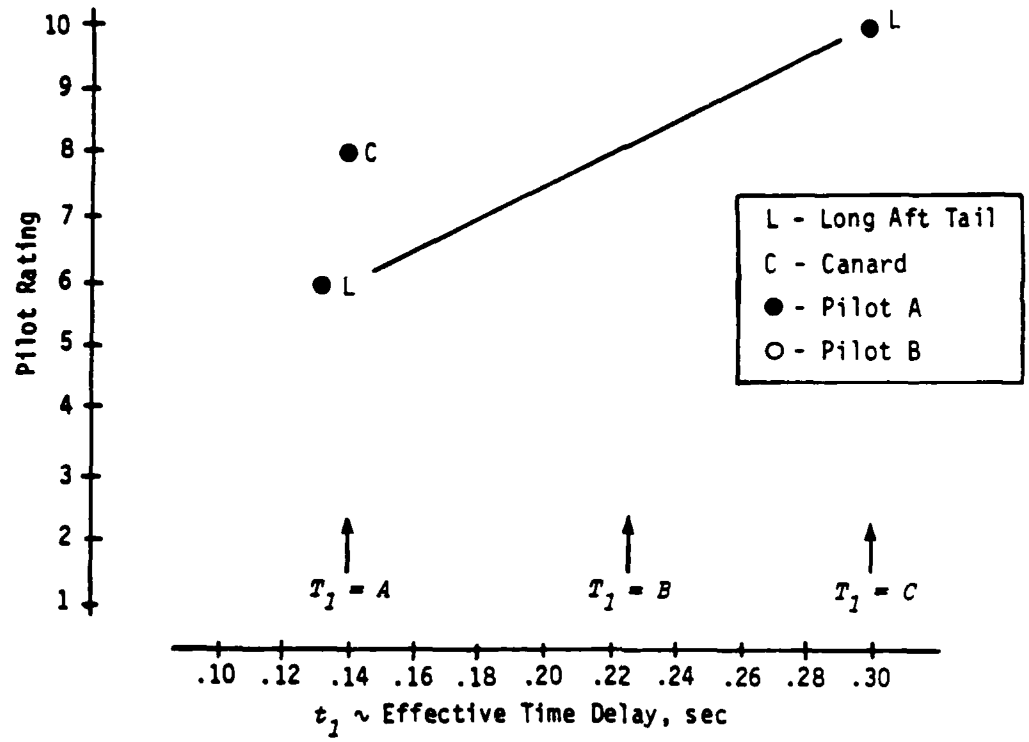


Figure 21. PILOT RATING VS EFFECTIVE TIME DELAY - UNAUGMENTED CONFIGURATIONS

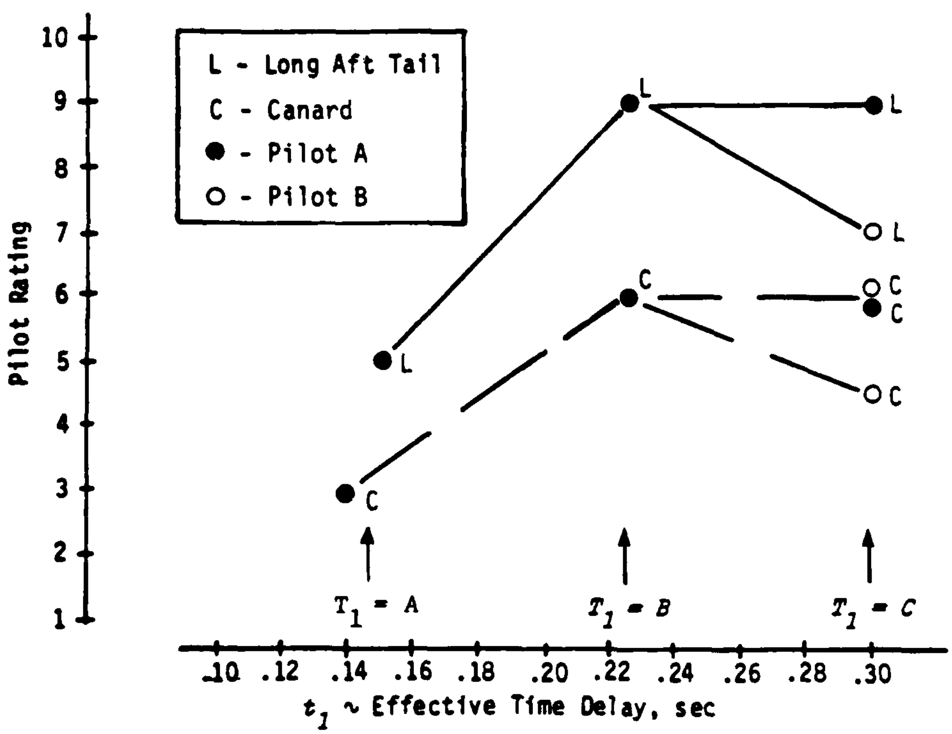


Figure 22. PILOT RATING VS EFFECTIVE TIME DELAY - LOW α FEEDBACK

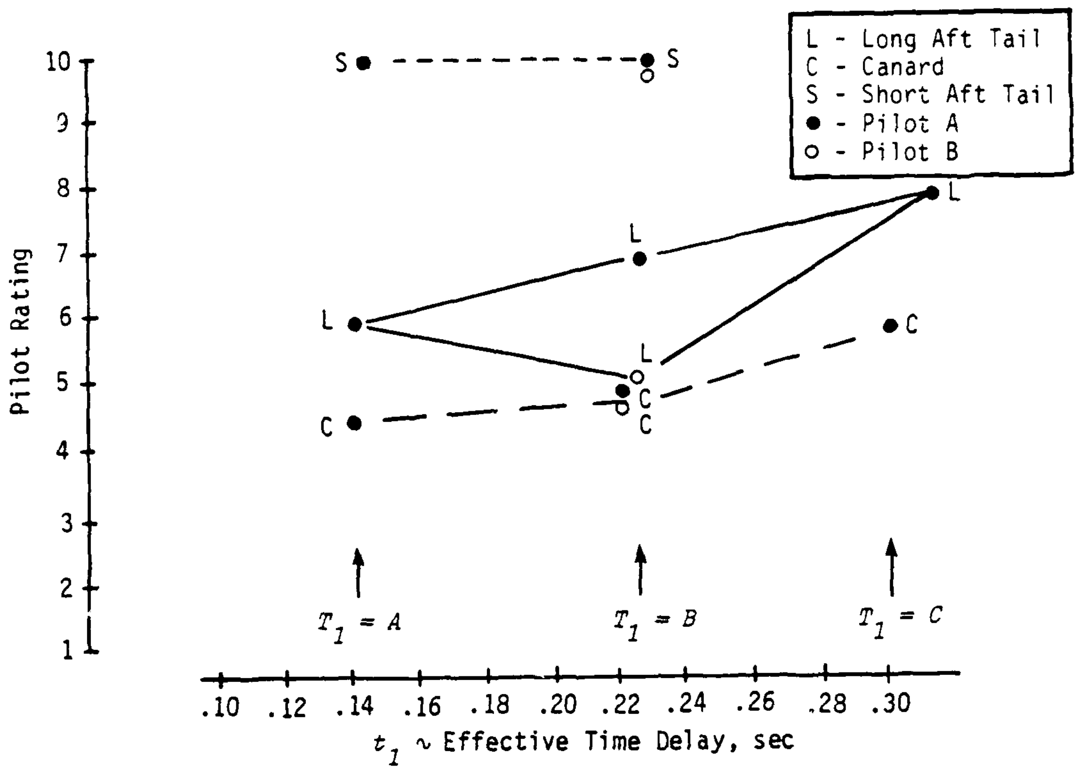


Figure 23. PILOT RATING VS EFFECTIVE TIME DELAY - MED. α FEEDBACK

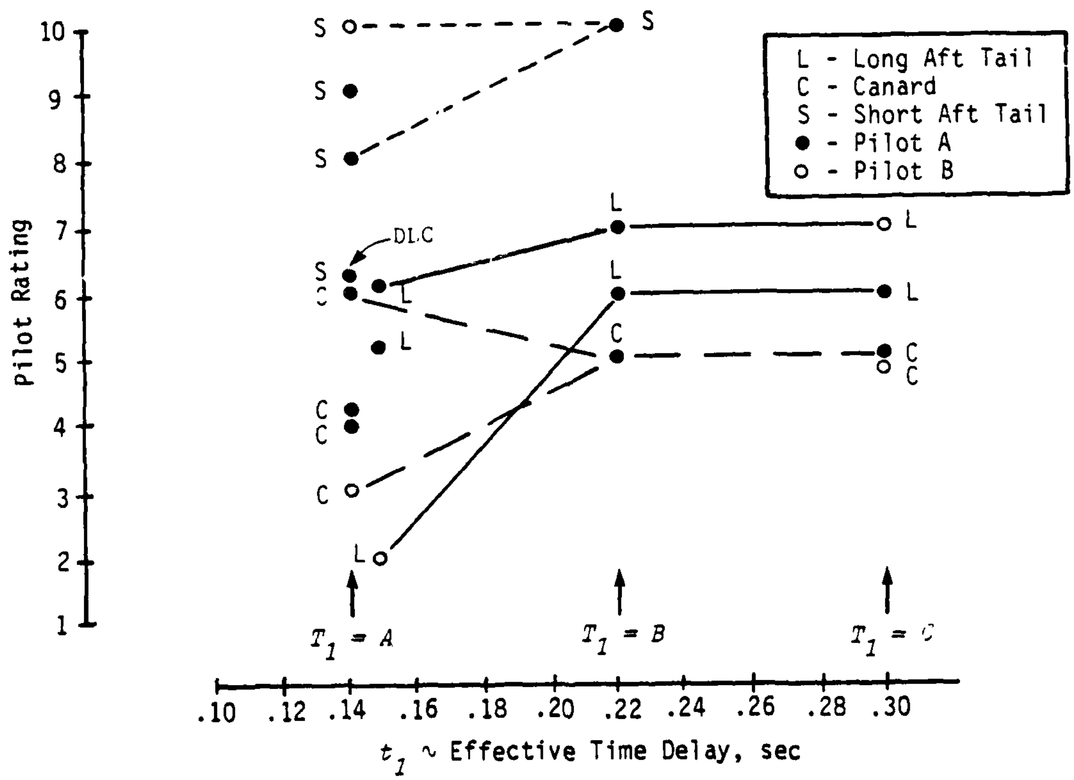


Figure 24. PILOT RATING VS EFFECTIVE TIME DELAY - HIGH α FEEDBACK

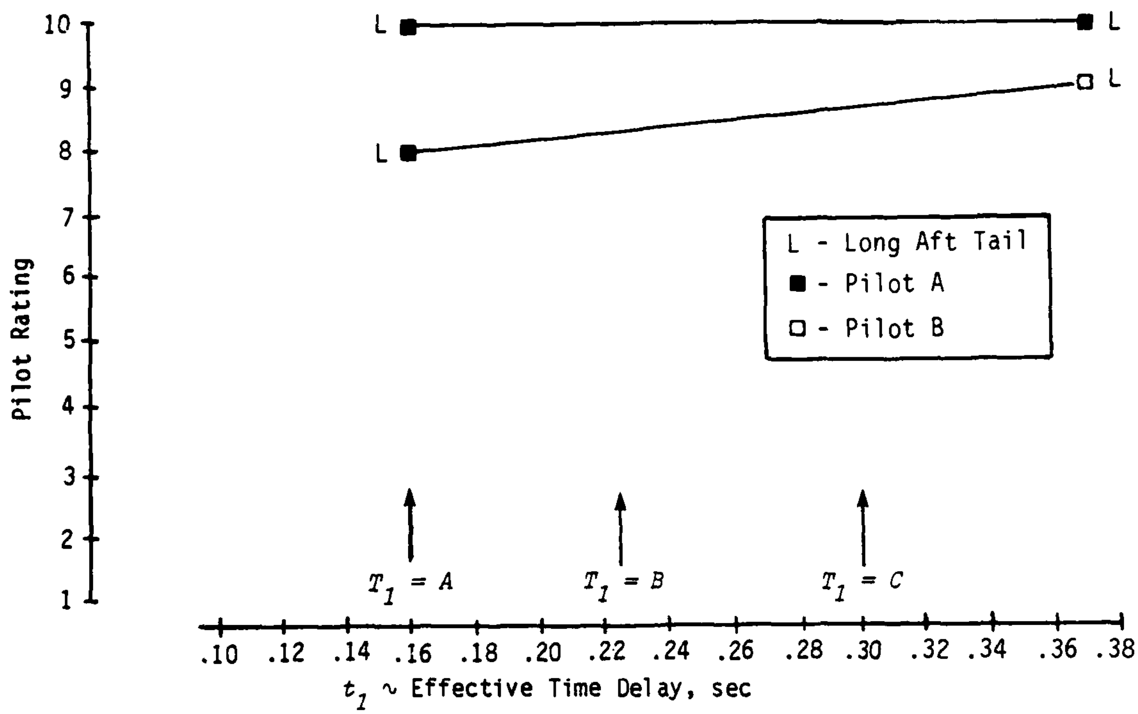


Figure 25. PILOT RATING VS EFFECTIVE TIME DELAY - LOW q FEEDBACK

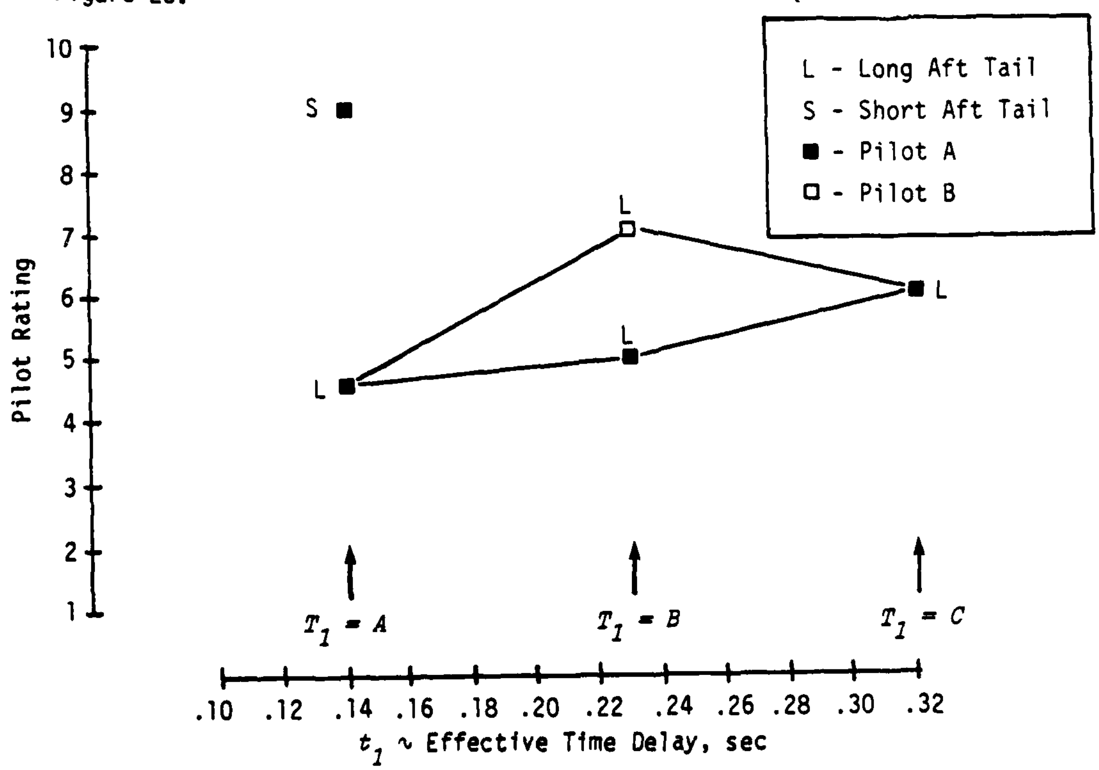


Figure 26. PILOT RATING VS EFFECTIVE TIME DELAY - MED q FEEDBACK

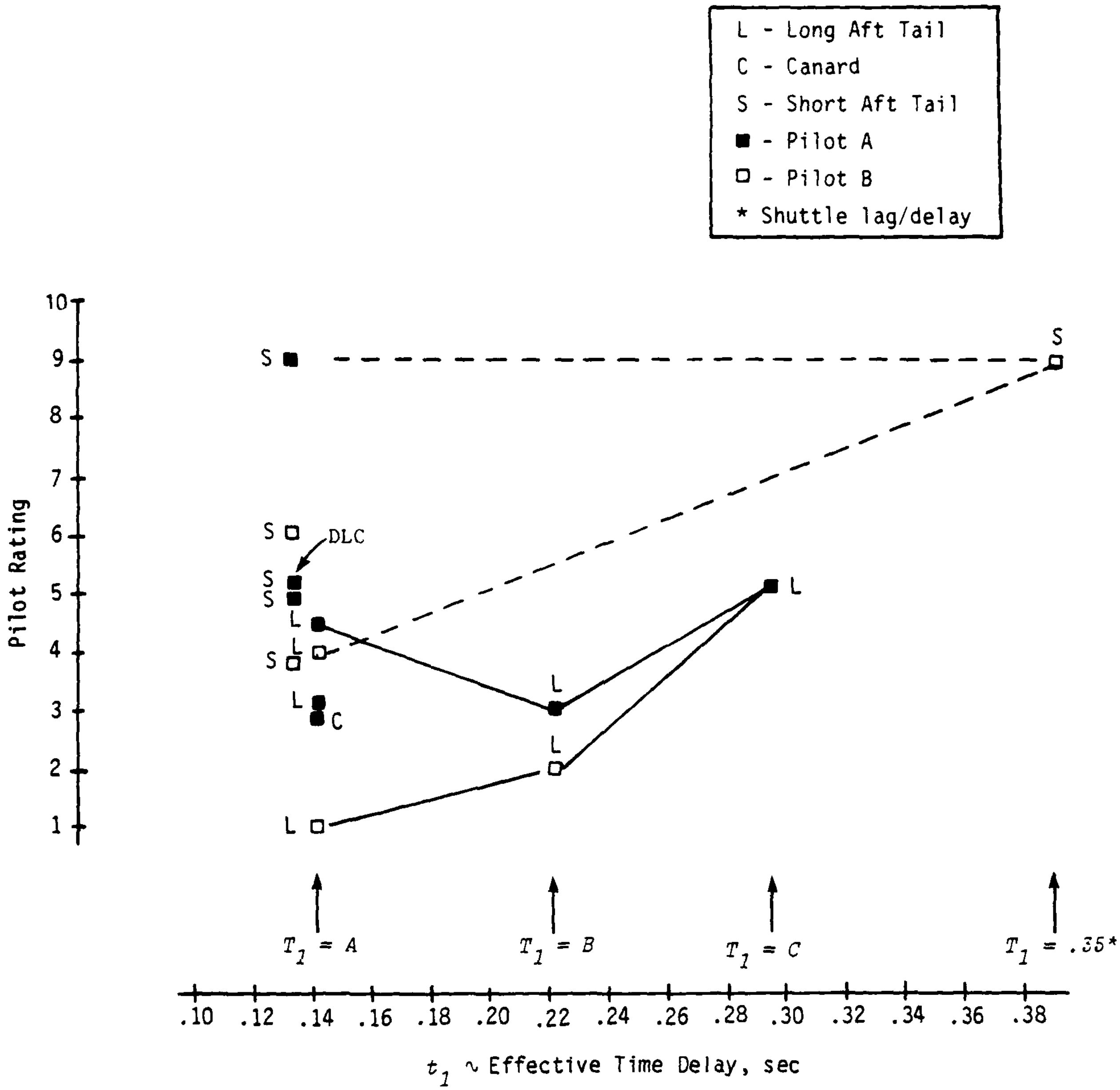


Figure 27. PILOT RATING VS EFFECTIVE TIME DELAY - HIGH q FEEDBACK

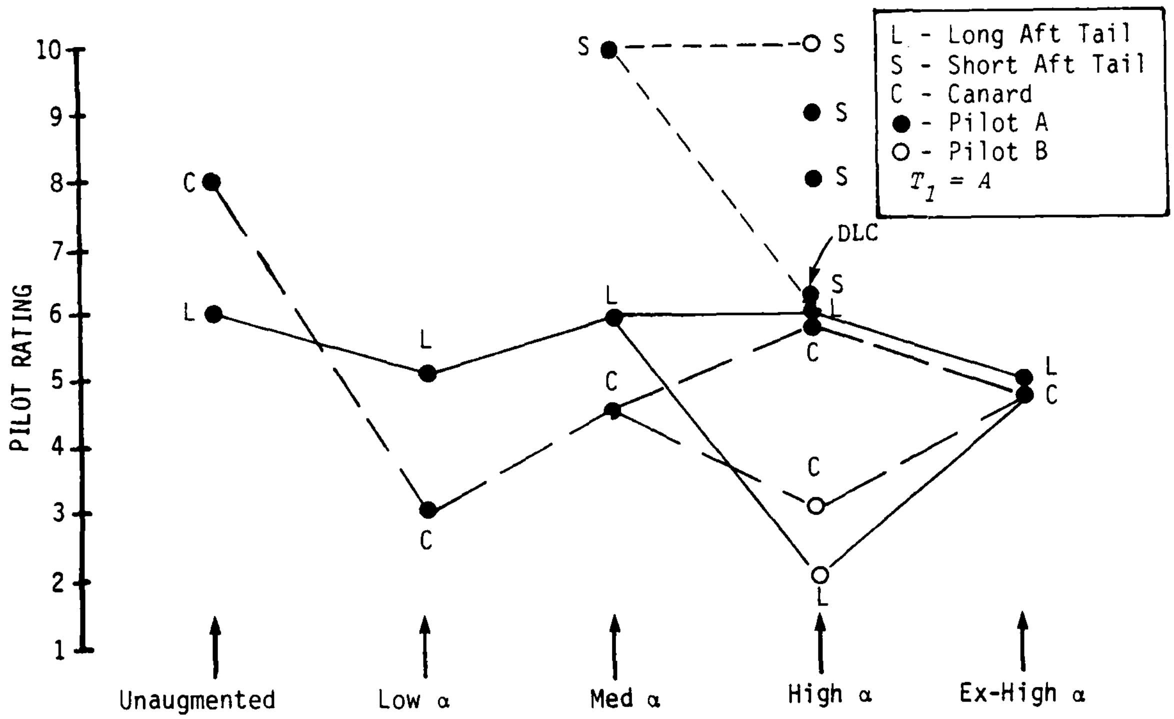


Figure 28. PILOT RATING VS LEVEL OF AUGMENTATION -α FEEDBACK

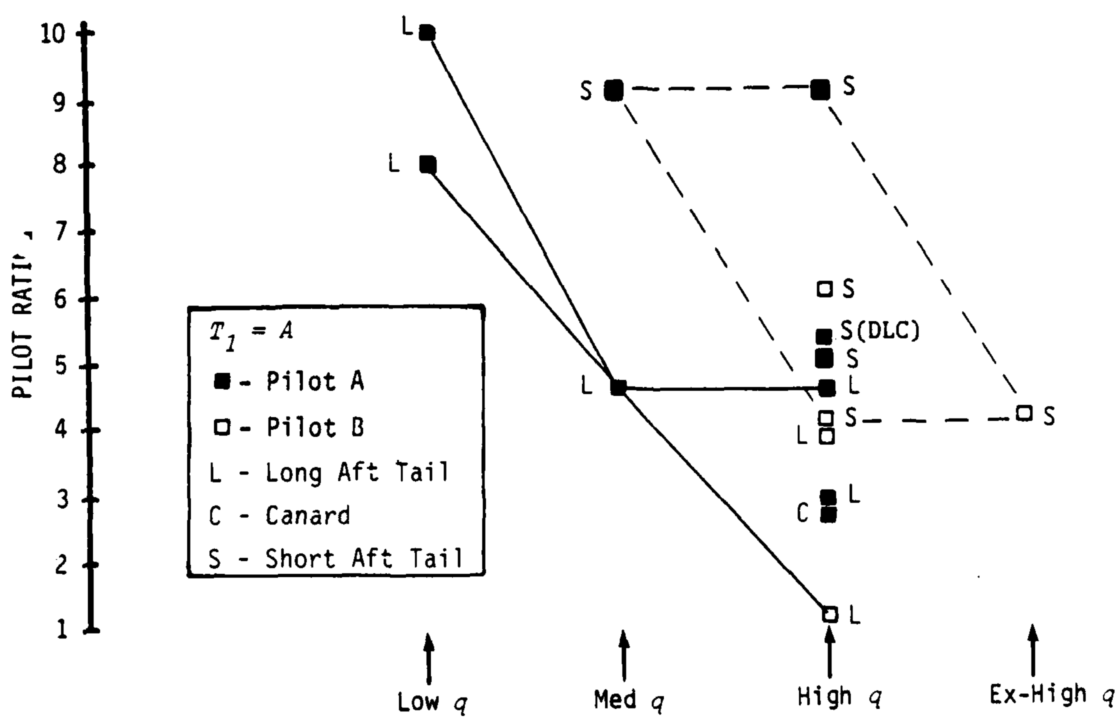


Figure 29. PILOT RATING VS LEVEL OF AUGMENTATION -q FEEDBACK

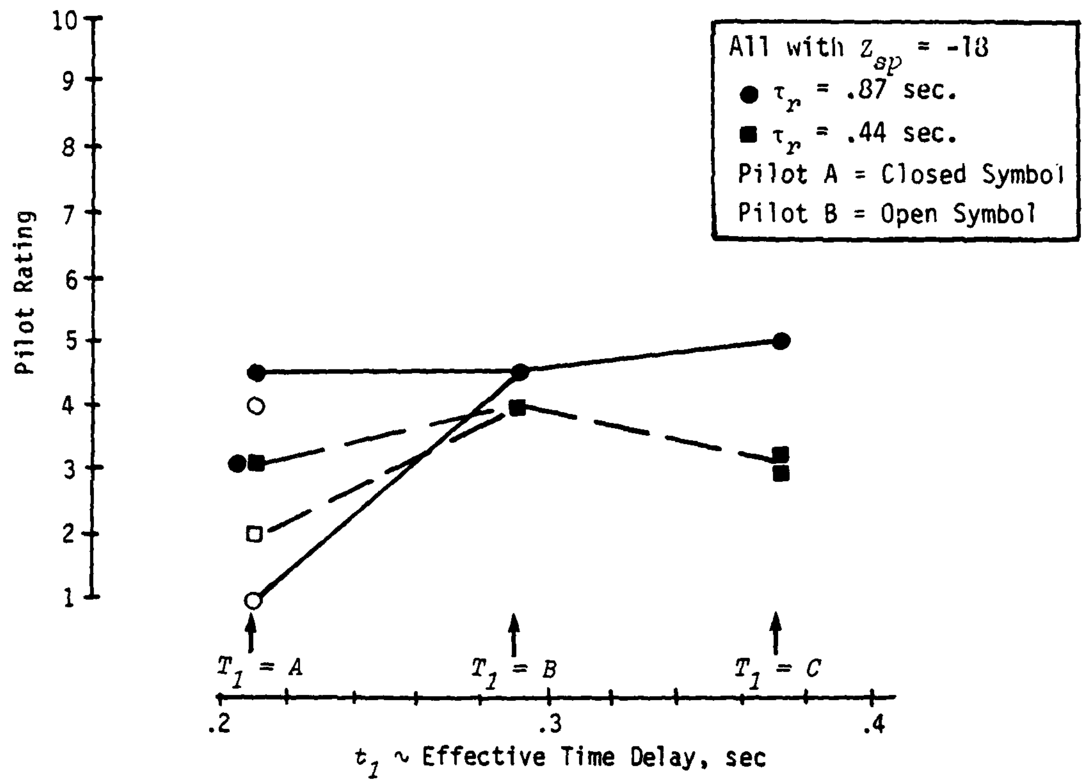


Figure 30. PILOT RATING VS EFFECTIVE TIME DELAY - LATERAL DIRECTIONAL

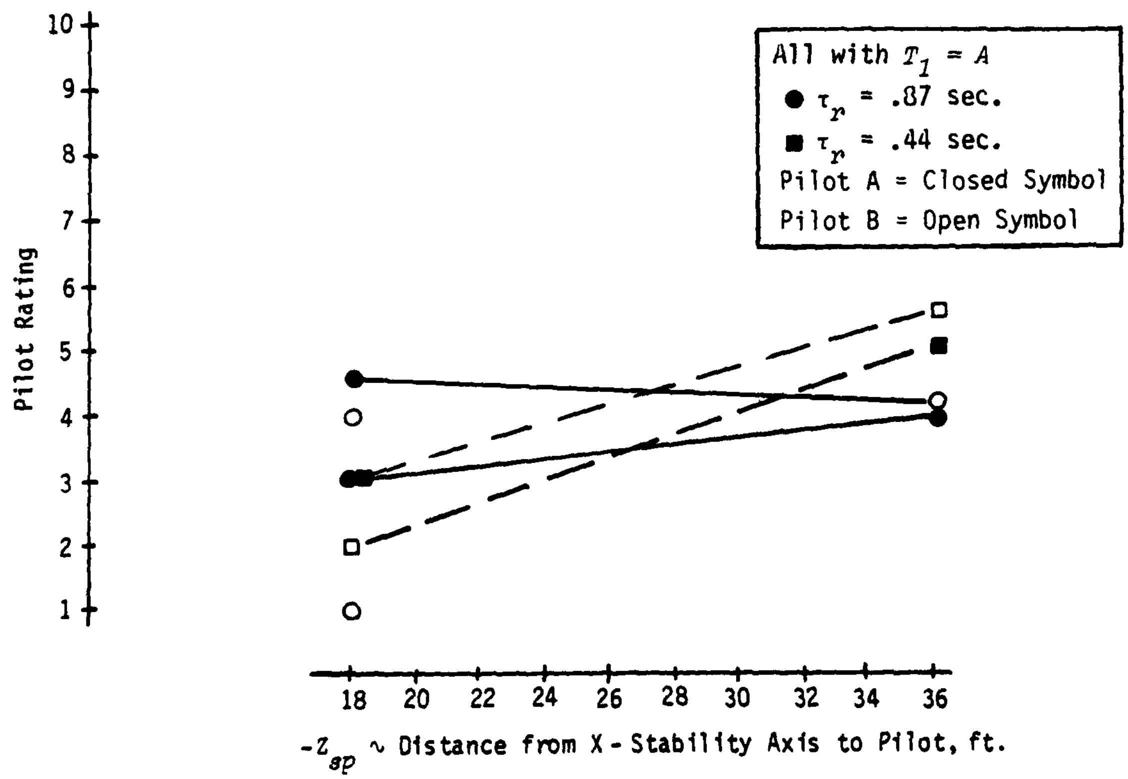


Figure 31. PILOT RATING VS PILOT POSITION ABOVE STABILITY AXIS (Z_{sp})

4.2.1 Longitudinal Results

The pilots noted problems with airspeed control on about two thirds of the evaluations. Airspeed problems occurred a little less often with q-augmentation than with α-augmentation and the problems were less severe for the higher augmentation gains than for the lowest gain configurations and the unaugmented airplane. For the latter cases, pitch control required so much attention that airspeed simply could not be given enough attention. There were very few cases, however, where pilot ratings of better than 3 were received even when there were no problems with pitch control. There may have been a one-to-two-point degradation in pilot rating due to the speed control problem. A number of factors can be identified which contributed to the airspeed control problems. The configurations were slightly on the backside, thus requiring active control of airspeed and thrust management in turns. The lag in thrust buildup following throttle inputs was long (a 3-second time constant) and the throttle position for trim was difficult to find. Together with turbulence, these factors caused airspeed to wander and made the response to throttle difficult to predict. Although low thrust-to-weight was not mentioned, the longitudinal acceleration/deceleration limit on the order of 0.1g may also have contributed to speed control problems.

The gradients of stick force with velocity about the trim speed were:

		dF_s/dV	
Augmentation	Long Aft Tail	Canard	Short Aft Tail
Unaugmented	+4.73 lb/kt	+4.64 lb/kt	
Low α	+0.03	+0.05	
Medium α	-1.29	-2.01	-1.86 lb/kt
High α	-5.67*	-5.55	-5.04
Extra High α	-11.43	-12.57	
All q	0	0	0

*-8.61 for $n/\alpha = 3$, -15.7 for $n/\alpha = 2$

Comparing the α- and q-feedback evaluations, the need for control-free static speed stability, dF_s/dV, cannot be substantiated.

Figure 20 shows how pilot ratings were affected by the variation of pilot position with respect to pitch center of rotation. The pilot position was varied from ten feet aft of the center of rotation in the Short Aft Tail configuration to 140 feet forward in the Canard. The data presented in Figure 20 is only the high level of augmentation cases with the low time delay level, $T_1 = A$. There is a definite trend towards better ratings as the pilot is positioned further forward of the center of rotation. This is more strikingly shown on some of the following figures where pilot ratings versus effective time delay and levels of augmentation are presented. On Figures 22, 23, 24, and 27 where the Low α, Medium α, High α, and High q configurations are presented respectively, the difference in pilot rating between the Long Aft Tail and Canard configurations is generally one to two. The differences in pilot ratings between the Long Aft and Short Aft Tail configurations are generally three to five.

This large variation in pilot ratings for configurations that were essentially the same except for pilot position is partly the effect of visual perception of rate of climb and altitude at the pilot position when near the ground and partly the effect of normal acceleration felt by the pilot. These cues are the normal acceleration at the pilot station and essentially the integrations of it. Normal acceleration at the pilot station is defined by:

$$n_{z_p} = n_{z_{c.g.}} + \frac{X_{MP}\dot{q}}{g}$$

Figure 32 presents the normal acceleration and altitude step responses for the three configuration designs (Long Aft Tail, Canard, Short Aft Tail), each for the High α augmentation level. The distances from the center of rotation to pilot position are +92.5, +140., -10. feet, respectively for these configurations. It can be seen that the Canard configuration has a 50% larger initial n_{z_p} kick than the Long Aft Tail configuration. The Short Aft Tail design produces a nonminimum-phase shape with the response initially going slightly negative before going positive and matching the other responses near three seconds into the time history. It is near one and one-half seconds into the response before the pilot can actually see his altitude change. The pilot comments

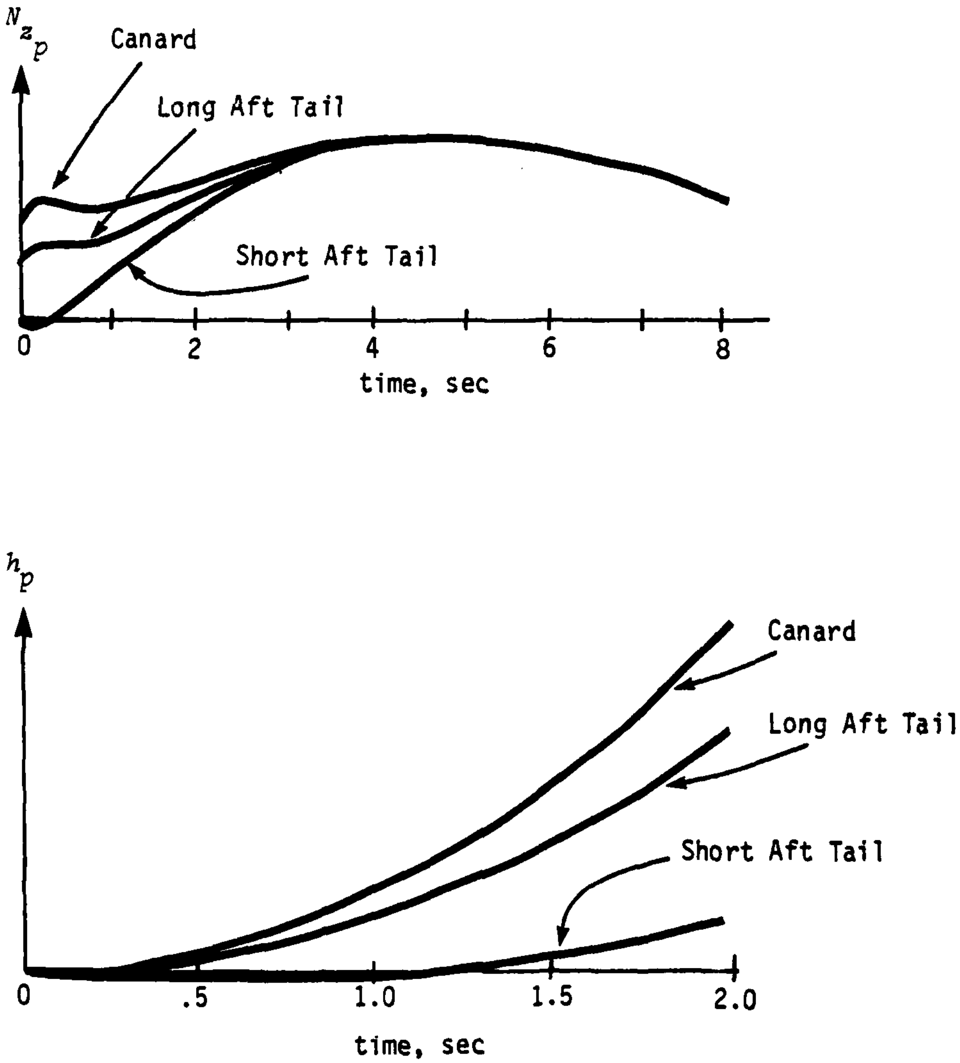


Figure 32. NORMAL ACCELERATION AND ALTITUDE AT PILOT STATION RESPONSES TO STEP INPUT, HIGH α AUGMENTATION, $T_1 = A$

clearly indicate that the pilots perceived this. With the Canard configuration, the pilots found they could fly the airplane more "naturally," the response felt more crisp and fine corrections in sink rate near touchdown were easily made. These comparisons are with respect to the Long Aft Tail configuration. The better perceived control over rate of sink, especially in the flare, overcame some of the problems related to the low short period frequency, sometimes described as ponderous, with the Long Aft Tail. The Short Aft Tail design was described as "very sluggish and delayed" even with the high augmentation levels and no extra lags or delays added. The ILS and VFR tracking away from the ground was described as all right but as soon as the pilot acquired outside cues for references in flare and touchdown, the control deteriorated. Many times, PIO's resulted. Comments indicated precise control of sink rate near touchdown was very poor or impossible. All of the pilot's attention was devoted to the altitude and rate of sink task with the touchdown point and lateral-directional task ignored many times.

The effect of time delay on pilot ratings had the expected overall trend (Figures 21 through 27). As the effective time delay (measured from the maximum slope intercept method — see Appendix V-B) increased from a level near .14 seconds to .30 seconds, pilot ratings degraded by one to three points. This degree of degradation was much less than expected based on experience in the landing experiment of Reference 6. This is especially true for the higher levels of augmentation where only a one to two rating point degradation was experienced. The degrading effect of time delay may not be as strong due to the low level of agility demanded by the pilots in this experiment. The task was to land a one-million pound transport aircraft with low turbulence response and strong ground effect. These characteristics and the low agility demanded by the pilot combine to yield an aircraft which can be landed using a significantly different technique than that required to land smaller aircraft. One of the pilots said he used a "learned" or "precognitive" attitude time history as reference for attitude control. This consisted of maintaining attitude constant until a certain wheel height and then making a specific noseup change of attitude, independent of sink rate or altitude, which he had learned would result in a good flare and acceptable sink rate at touchdown. He depended on

the ground effect to provide a significant amount of the lift required to arrest the sink rate. He claims this technique is more open loop in terms of use of h and $\dot{h}$ cues than the technique used to land smaller aircraft. With the control technique used, which is commonly used for very large aircraft, the pilot is more tolerant of, or less sensitive to, time delays inserted in the command path. This is discussed further in Section 4.5. The Short Aft Tail design was rated poorly even with the low level of time delay. The effect of increasing the time delay was not evident for these configurations.

Part of the increased tolerance to control system lag and delay when the pilot was located large distances ahead of the center of rotation is thought to be attributable to the pitch acceleration response. Although delayed, pitch acceleration is amplified and "displayed" to the pilot as normal acceleration. The amplified initial normal acceleration response is easily perceived by the pilot and provides the needed confirmation cue that the airplane is responding to the pilot's control action.

In the Canard configuration, the abrupt normal acceleration at the pilot station due to pitch acceleration overcomes the problems due to effective delay. The pilot comments indicate that they usually did notice the increased delay when it was added for these configurations, especially during the IFR portion of the approach. However, they had the feeling they were getting a response that was predictable. This was unlike the Long Aft Tail configurations with the extra delay added, where the pilots more readily complained about the lagged response and poor predictability. For the Short Aft Tail configurations, there are many points in the Level 2 region which have pilot ratings worse than 6.5 even for the minimum time delay. Again, it appears that the pilot position aft of the center of rotation causes this. There were pilot comments describing delayed response and altitude control problems in flare when there was no extra lag added. The Short Aft Tail configurations for which extra lags and delays were inserted in the command path received pilot ratings of 9 and 10 and PIO ratings of 4, 5, and 6. These latter configurations were similar to Canard configurations (except for the changes to move the pilot position with respect to the center of rotation) which received pilot ratings of 5 and 6 and PIO ratings of no worse than 3.

the ground effect to provide a significant amount of the lift required to arrest the sink rate. He claims this technique is more open loop in terms of use of h and $\dot{h}$ cues than the technique used to land smaller aircraft. With the control technique used, which is commonly used for very large aircraft, the pilot is more tolerant of, or less sensitive to, time delays inserted in the command path. This is discussed further in Section 4.5. The Short Aft Tail design was rated poorly even with the low level of time delay. The effect of increasing the time delay was not evident for these configurations.

Part of the increased tolerance to control system lag and delay when the pilot was located large distances ahead of the center of rotation is thought to be attributable to the pitch acceleration response. Although delayed, pitch acceleration is amplified and "displayed" to the pilot as normal acceleration. The amplified initial normal acceleration response is easily perceived by the pilot and provides the needed confirmation cue that the airplane is responding to the pilot's control action.

In the Canard configuration, the abrupt normal acceleration at the pilot station due to pitch acceleration overcomes the problems due to effective delay. The pilot comments indicate that they usually did notice the increased delay when it was added for these configurations, especially during the IFR portion of the approach. However, they had the feeling they were getting a response that was predictable. This was unlike the Long Aft Tail configurations with the extra delay added, where the pilots more readily complained about the lagged response and poor predictability. For the Short Aft Tail configurations, there are many points in the Level 2 region which have pilot ratings worse than 6.5 even for the minimum time delay. Again, it appears that the pilot position aft of the center of rotation causes this. There were pilot comments describing delayed response and altitude control problems in flare when there was no extra lag added. The Short Aft Tail configurations for which extra lags and delays were inserted in the command path received pilot ratings of 9 and 10 and PIO ratings of 4, 5, and 6. These latter configurations were similar to Canard configurations (except for the changes to move the pilot position with respect to the center of rotation) which received pilot ratings of 5 and 6 and PIO ratings of no worse than 3.

Pilot ratings versus level of augmentation are presented in Figures 28 and 29 for α and q augmentation, respectively. There is a slight trend towards better ratings as the α augmentation level is increased. The trend to better ratings is much more pronounced with the q augmented configurations. With the α augmented configurations, as the feedback was increased, the short period frequency increased progressively making the configuration stable and then increasingly quicker and responsive. However, along with the higher level of static stability came some non-beneficial characteristics. Large forces were required to hold speeds off of trim and to keep the aircraft level in turns where large angle of attack changes were necessary. In addition, as the stability increased, so did the the turbulence response as discussed in Section 4.6. The pilots commented that these higher-augmented configurations had better initial response characteristics but did not seem to hold attitude, and predictability of final attitude was not as good as desired. Attitude, airspeed and flight path control required high workload in turbulence.

The α-augmented airplanes tended to hold α and, in turbulence and ground effect there was considerable low-frequency variation of attitude and airspeed which required increased pilot attention and workload to control. The airplanes were repeatedly described as ponderous in the IFR approach and difficult to control in the flare and touchdown. The phugoid mode, which becomes less damped and moves to higher frequency as α feedback is increased ($\zeta_{ph} = .037$, $\omega_{ph} = .15$ rad/sec for the Extra-High α configuration), becomes more noticeable and is likely the cause of these observations and the pilot rating of 5 for the Extra-High α configurations.

The q-augmented configurations generally had better pilot ratings and comments than the α-feedback configurations as the level of augmentation increased. (An exception to the Pilot A evaluation of the High q-configuration performed on 8/4/80. See Pilot Comments on page 256. This evaluation was performed with a tail wind and may have been influenced by wind shear.) The primary reason for this is the attitude hold feature for these q-feedback configurations. This made precise control of pitch attitude much easier near touchdown because the control system rejected pitch disturbences due to ground effect. The pilots could make a small input and know where the final attitude would be. This was especially helpful with the Short Aft Tail configuration which did not provide the necessary motion cues to tell the pilot he had

made the proper corrections. He could learn to fly with an open-loop technique making small occasional pulse-like inputs to correct flight path errors. The pilots were favorably impressed with the level turn feature without pitch inputs in the q-augmented configurations. See Figure 4. This completely eliminated the fatigue resulting from turning maneuvers with the higher α-augmented configurations. Turbulence response, which is discussed in Section 4.6, was also much less with these q-feedback configurations due to the low static stability of the basic airplane and the tendency of the control system to hold attitude and zero pitch rate. When the pitch rate augmented airplanes were "trimmed" and the pilot had the right thrust setting, they tended to hold airspeed very well, even in turbulence.

The reduced n_z/α configurations with the High-α augmentation received ratings of 4-1/2 and 6 for $n_z/\alpha = 3$, and 5-1/2 and 7 for $n_z/\alpha = 2$. The value of 2 was chosen to lie on the Level 1 boundary of the MIL-F-8785C ω_{sp} vs n_z/α criteria. These ratings were definitely Level 2, but most of the detrimental comments concerned the large increase in elevator forces and large increase in thrust required in turns due to the large change in angle of attack required. The pitch dynamics and maneuverability characteristics of these configurations were satisfactory. If a pitch compensator (as on the q-augmented configurations) and more thrust were available, these configurations would probably have received higher ratings.

4.2.2 Lateral-Directional Results

Table VIII lists the important lateral-directional characteristics of the configurations evaluated. Included on this table are values for the parameter:

$$\left.\frac{n_{y_{pilot_{max}}}}{p_{max}}\right|_{\substack{step\ input \\ t\,<\,2.5\ sec}}$$

TABLE VIII

LATERAL-DIRECTIONAL CHARACTERISTICS

(All flown with longitudinal characteristics set up for Long Aft Tail, High q-feedback, $T_1 = A$)

$\zeta_d = .57$ $\qquad \zeta_d \omega_d = .279$

$\omega_d = .49$ *rad/sec*

$|\phi/\beta|_d = 1.28$

$\tau_s = 300$ *sec*

τ_R, sec (Roll Mode Time Constant)	Z_{sp}, ft (Stability Axis to Pilot Position	$\dfrac{n_{y_{pilot_{max}}}}{p_{max}}$ Step Input, $t < 2.5$ sec, g's/rad/sec (Lateral Acceleration Parameter)	Time to $\phi = 30^o$, sec ($\delta_{a_{max}} = 100^o$)
.87	-18	.48 (T_1=A), .41 (T_1=B,C)	2.2
.44	-18	.80 (T_1=A), .59 (T_1=B,C)	3.0
.87	-36	1.03 (T_1=A)	2.2
.44	-36	1.72 (T_1=A)	3.0

Actual effective time delays measured from maximum slope intercepts with feel system included for the various levels of delay flown are:

Level of Delay (T_1)	t_1 — Actual Effective Time Delay, sec
A	.21
B	.29
C	.37

which is a measure of the lateral acceleration produced with roll inputs (Reference 3). The configurations were generally Level 1 according to MIL-F-8785C requirements with respect to Dutch roll, roll, and spiral characteristics. The effective time delays (measured by the maximum slope intercept method - Appendix V-B) were at or worse than the Level 2 boundary from MIL-F-8785C (Level 1 = .1, Level 2 = .2, Level 3 = .25 seconds) and the recommended Supersonic Cruise flying qualities design criteria (Level 1 = .17, Level 2 = .24, Level 3 = .28 seconds).

Pilot ratings versus effective time delay are presented in Figure 30. It can be seen that there is very little effect on pilot ratings for the relatively large levels of delay utilized. However, the pilots noted a slight overcontrol tendency with the high time delays. There was a slight improvement of about one rating point with the faster roll mode time constant. The tolerance of the large time delays may be due to the low agility of the task as performed by the pilots and the otherwise very good lateral-directional flying qualities of the configurations. Turns were automatically coordinated, so sideslip and the Dutch roll mode were not excited with roll inputs. There were some complaints due to the low Dutch roll frequency (.5 rad/sec) which made the pilots call the configuration "ponderous" when they had to use yaw control as in the sidestep maneuver, and crosswind and turbulence corrections. Directional trimming was difficult, they had to put in a trim correction and wait 4 - 5 seconds to see what happened. Generally, the lateral-directional characteristics were not a factor in the evaluations. Another reason for the small effect of time delay is that the linear acceleration cues at all the pilot positions evaluated provided sufficient initial response cueing to alert the pilot that his input was producing a response.

To gather data on the effect of lateral acceleration on pilot ratings, two pilot positions (18 feet and 36 feet above the X-stability axis) along with the two roll mode time constants were evaluated. Figure 31 presents pilot ratings versus pilot position for these configurations. The trend toward worse ratings is evident as the pilot moves higher above the roll axis. In Reference 3, a lateral acceleration parameter,

$$\left.\frac{n_{y_{pilot_{max}}}}{p_{max}}\right|_{\substack{\text{step input} \\ t\,<\,2.5\ \text{sec}}},$$

was developed which correlated well with pilot ratings. This parameter shows the degradation in pilot ratings expected due to lateral acceleration in an otherwise satisfactory configuration. Figure 33 presents the results from the present experiment along with those from Reference 3 . For the configurations with the pilot in the lower position (Z_{sp} = -18 feet), the lateral acceleration parameter had Level 1 values. With the pilot at the higher position (Z_{sp} = -36 feet) with the higher roll damping, the lateral acceleration parameter increased to a middle Level 2 value and the pilot ratings verified this. The pilot comments indicate that the pilots could easily sense the higher lateral acceleration. They noted that the ride became jerky with roll inputs and the side acceleration environment was "disorienting." There was a tendency for the pilot's roll inputs to couple with the acceleration and set up a ratcheting or oscillating motion. It was more than just a ride qualities prolem, as their ability to do the task was affected. They dropped their pilot ratings of the flying qualities to 5 and 5-1/2 from the 3 and 2 received with the pilot at the lower position.

Adding a prefilter to the roll command did not have an effect on pilot rating with the pilot at the lower position (Z_{sp} = -18 feet). Although not evaluated with the pilot in the higher position (Z_{sp} = -36 feet), it can be speculated that the prefilter may have smoothed the pilot's inputs and, therefore, reduced the lateral acceleration kicks for these configurations.

4.3 PITCH ATTITUDE PILOT/AIRCRAFT CONTROL LOOP ANALYSIS

4.3.1 Introduction

Analysis of the pitch-attitude pilot/aircraft control loop was performed on the evaluated configurations. These included open-loop analysis of the aircraft alone without pilot: θ/F_{ES}, open-loop analysis of aircraft plus pilot without any pilot compensation: $\theta/\theta_{\varepsilon}$ (no compensation), and closed-loop analysis of entire pitch attitude control system with pilot compensation. The pitch attitude control loop structure is shown in Figure 34. Results from

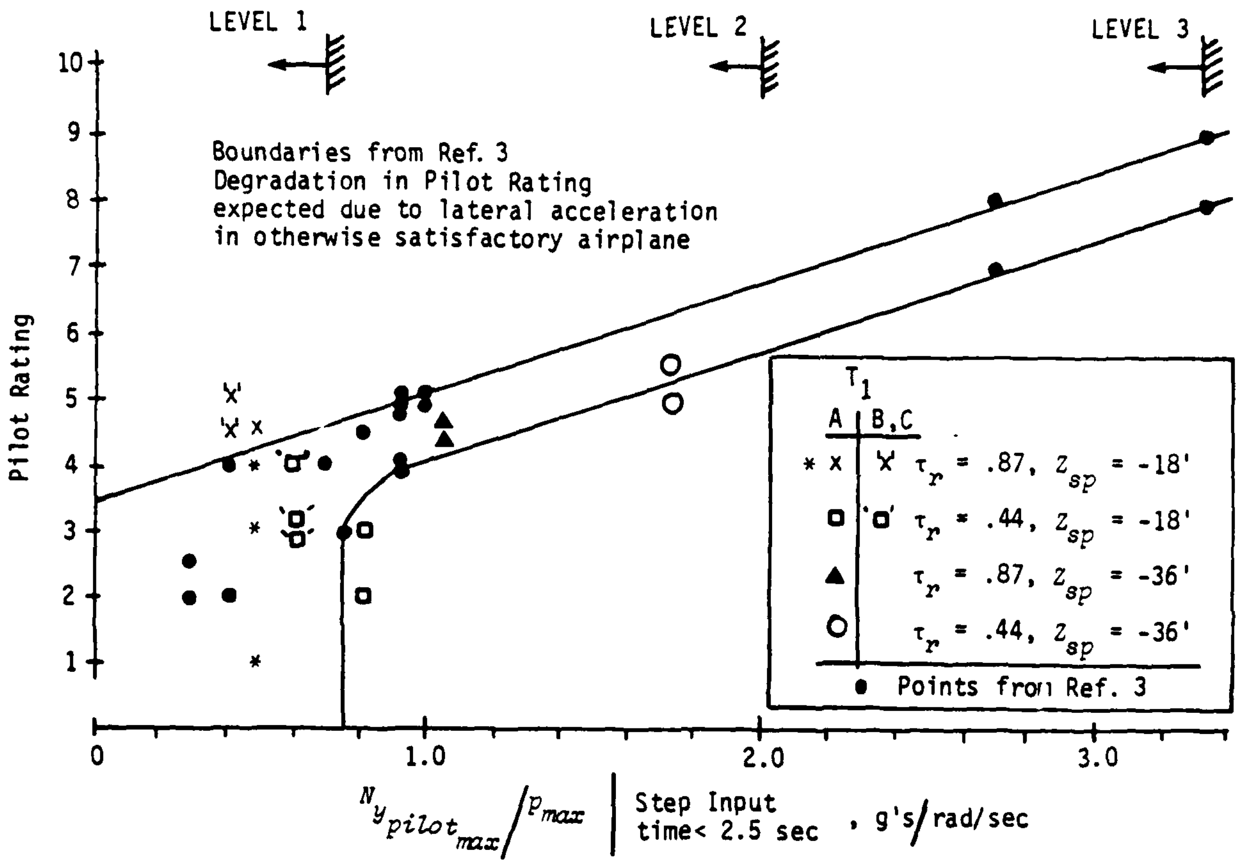


Figure 33. PILOT RATING VS LATERAL ACCELERATION CRITERIA

Note: The three * points are from the baseline configuration Long Aft, High q, T_1=A; Pilot A - one point, Pilot B - two points. These were evaluated during the longitudinal variations and no lateral-directional comments were made.

the open-loop aircraft configuration and uncompensated pilot analysis are presented in Appendices V-C and V-D. The closed-loop analysis is presented here.

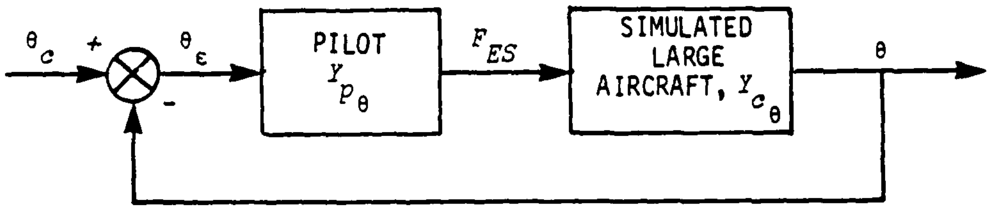


Figure 34. PITCH ATTITUDE CONTROL LOOP STRUCTURE

The analysis is derived from the work by Neal and Smith reported in Reference 5. The basic approach is to model the pilot-airplane pitch attitude control loop as a unity feedback system with a pilot model of an assumed form in the forward loop. The form of the assumed pilot model permits accounting for the following characteristics exhibited by pilots when controlling dynamic systems:

- Adjustable gain.
- Time delay.
- Ability to develop lead or to operate on derivative or rate information.
- Ability to develop lag or to "smooth" inputs. (Lag was not used for the configurations investigated because it would not improve the closed-loop dynamics).
- Ability to provide low frequency integration.

The form of the pilot model defined below accounts for the observed capabilities and limitations of the pilot with sufficient accuracy to permit approximate analysis of the dynamics of the closed-loop, pilot-airplane system in pitch. It should be emphasized that it is not necessary for the pilot model to be an exact analog of the human pilot for it to be useful in the context of

design criteria. The design criteria are based on the hypothesis that if good closed-loop dynamic performance can be achieved with an autopilot of the form described by the assumed pilot model, then the human pilot will also be able to achieve good closed-loop dynamic performance.

The pilot model used is:

$$Y_{P_\theta} = K_{P_\theta} e^{-.25s} \left(\frac{5s+1}{s}\right)(\tau_L s+1)$$

The gain, K_{P_θ}, is in the units of pounds/rad - sec.

The $e^{-.25s}$ term accounts for time delay in the pilot's neuromuscular system. The value of 0.25 sec. is based on delays observed in records for the discrete tracking task performed in References 5 and 6. These records exhibit delays ranging from 0.20 to 0.40 seconds. The value of 0.25, selected on the basis of cut and try data correlation, is interrelated with the bandwidth frequency that is specified for a given flight phase or task.

The $\frac{5s+1}{s}$ term provides low-frequency integration capability. A form of the pilot model without this term can be used when constant-speed or two-degree-of-freedom equations are used to represent the airplane. In that case, the airplane transfer function should have a free s in the denominator and low-frequency integration by the pilot will not be necessary. When three-degree-of-freedom equations are used, as is the case in the present analysis, or when the flight control system uses high-gain attitude stabilization, it may be necessary for the pilot model to perform low-frequency integration to avoid droop at frequencies less than ω_{BW}. The 5 sec. lead term permits using integration to avoid the droop limit at low frequency but will not significantly affect the short term dynamics of primary interest.

The $(\tau_L s+1)$ term accounts for the lead that the pilot provides to achieve desired closed-loop performance and is a measure of his workload.

Because the closed-loop,pilot-airplane dynamic system has been modeled as a negative feedback system with unity gain in the feedback path, it is possible to relate the dynamic characteristics of the elements in the forward loop, $\theta/\theta_\varepsilon = Y_{p_\theta} Y_{c_\theta}$, to the dynamic characteristics of the closed-loop system, $\theta/\theta_c = \frac{Y_{p_\theta} Y_{c_\theta}}{1+Y_{p_\theta} Y_{c_\theta}}$, through use of a Nichols diagram, (Figure 35). This diagram consists of the superposition of two grid systems. The rectangular grid is the magnitude and phase of the forward-loop dynamic elements, $Y_{p_\theta} Y_{c_\theta}$, and the curved grid system represents the magnitude and phase of the closed-loop system $\theta/\theta_c = \frac{Y_{p_\theta} Y_{c_\theta}}{1+Y_{p_\theta} Y_{c_\theta}}$. Therefore one can determine the closed-loop dynamic characteristics by plotting the magnitude and phase data of $Y_{p_\theta} Y_{c_\theta}$ for a range of frequency on the rectangular grid.

It is hypothesized that a given Flight Phase or task performed in a typical environment will require certain minimum dynamic characteristics of the closed-loop,pilot-airplane system. The parameters used to define the closed-loop dynamic performance are bandwidth, droop at frequencies below the band width,and resonance magnitude. These closed-loop system parameters are defined by the curved lines on Figure 35. The maximum droop permitted for $\omega < \omega_{BW}$ is -3.0 db. This value has been defined somewhat arbitrarily but can be justified from examination of discrete tracking task records in References 5 and 6 and by interpretation of pilot comments in these references (ω is a parameter which varies as shown along the amplitude-phase curve).

The closed-loop system resonance limits for Level 1 and Level 2 have been determined from empirical data correlation.

The bandwidth frequency is dependent upon the task.

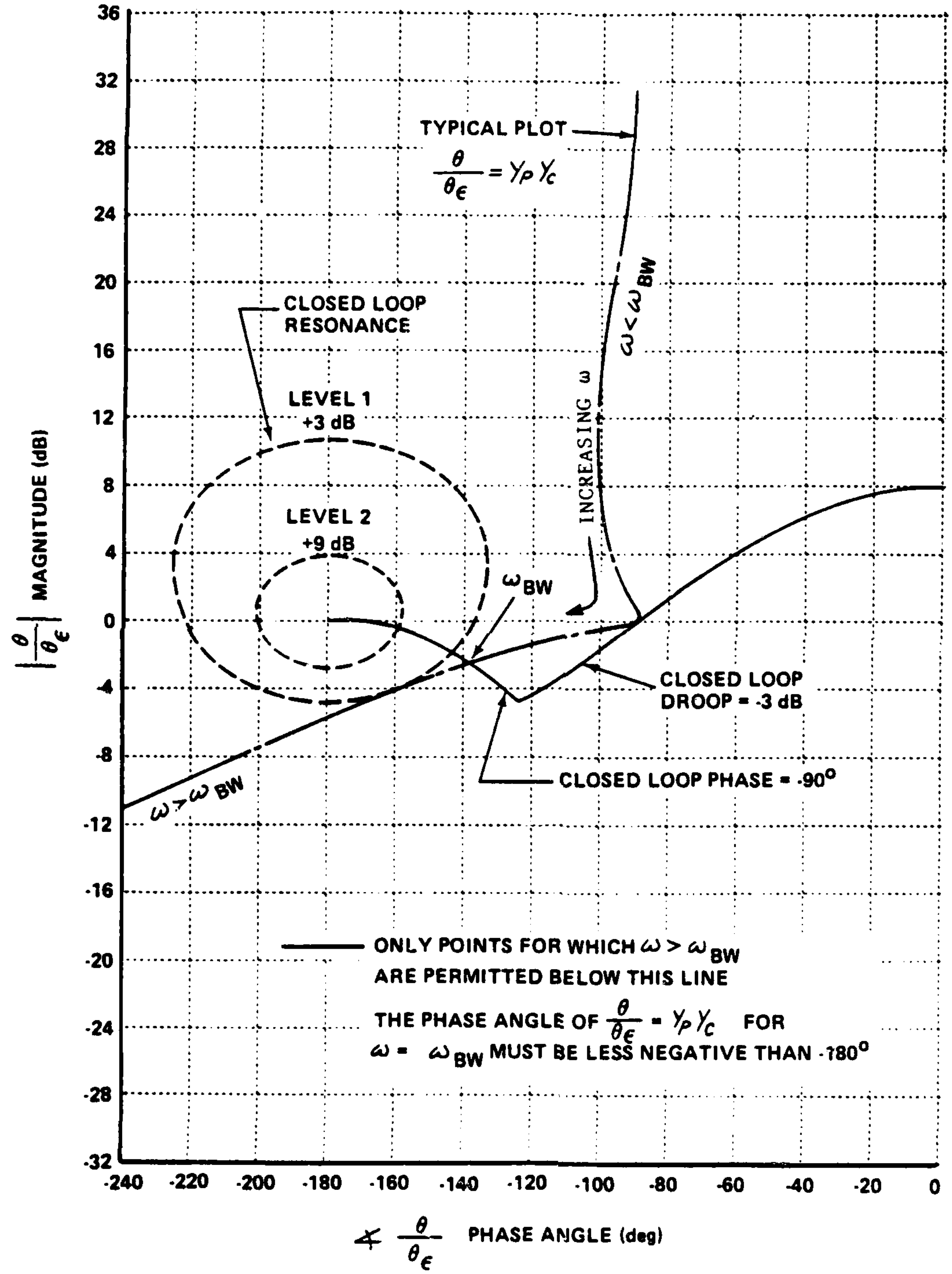


Figure 35. DESIGN CRITERIA FOR PITCH DYNAMICS WITH THE PILOT IN THE LOOP

In application of these design criteria, the designer must succeed in finding a combination of K_{p_θ} and τ_L which will cause the amplitude and phase data for $Y_{p_\theta} Y_{c_\theta}$ to plot in the Level 1 or Level 2 regions of Figure 35. It is necessary, therefore, to perform a parameter search. This search procedure is not difficult; it can be performed graphically using graphical aids described in Reference 5 or the process can be mechanized on a digital computer. Because the calculations involved in evaluating the magnitude and phase of $Y_p Y_c$ as a function of frequency are simple to perform, it is feasible to use a simple trial and error approach to test whether or not a proposed airplane design meets the design criteria for closed-loop performance.

4.3.2 Pilot Compensation (Neal-Smith) Analysis

In this analysis, pilot lead compensation $(\tau_L s+1)$ was obtained that would make the open-loop compensated pilot plus aircraft transfer function $(\theta/\theta_\varepsilon)$ drawn on a Nichols diagram pass through the acceptable closed-loop criteria region (see Figure 35). That is, find the appropriate gain and lead to keep closed-loop resonance less than +3 dB and closed-loop droop less than -3 dB for $\omega < \omega_{BW_\theta}$. The bandwidth frequency is defined as the frequency which results in a closed-loop phase of -90 degrees. The bandwidth chosen for this set of data was 1.5 rad/sec. This value of bandwidth resulted from correlation of the PR $\leq$ 3.5 data with pilot lead compensation of approximately 45° or less. This value of bandwidth appears appropriate for the task of landing a very large transport in a manner which does not require high agility of the closed-loop pilot-airplane system.

To obtain the pilot compensation, lead was added to force the 1.5 rad/sec point through the -90 deg. closed-loop phase line with the $\theta/\theta_\varepsilon$ plot just skimming the +3 dB closed-loop resonance boundary. The resulting closed-loop droop was much less than -3 dB (near 0 dB) for most configurations. Lower resonance could have been obtained with the droop still not dropping below -3 dB

by using more lead compensation. The solutions chosen, therefore, represent minimum pilot lead required to meet the performance standard. The maximum lead time constant used was approximately 7 seconds. This results in lead of: $\tan^{-1}(\tau_L \omega_{BW_\theta}) = 85$ degrees at the 1.5 rad/sec bandwidth. This limit is arbitrary but represents the situation of diminishing returns that occurs in the closed-loop system, i.e., extreme increases in pilot lead do little to improve closed-loop performance. For a few cases, the performance criterion of less than 3 dB resonance could not be achieved with this maximum lead.

The aircraft (with the 25 rad/sec feel system) plus compensated-pilot, open-loop $\theta/\theta_\varepsilon$ transfer functions for each configuration evaluated are presented in Appendix IV. The lead time constant in seconds, phase compensation at the bandwidth ($\measuredangle PC = \tan^{-1} 1.5\, \tau_L$), and pilot gain are presented in Table IX. Plots of pilot rating versus the pilot compensation, $\measuredangle PC$, are presented in Figures 36 through 38. All of pilot B's ratings are included although many were performed using the 15 rad/sec feel system.

There is a definite trend towards worse pilot ratings as more pilot compensation is required. From the Long Aft Tail and Canard configurations data, it appears that the phase compensation must be less than 55 degrees for Level 1 ratings and less than 75 degrees for Level 2 ratings. The points with large pilot compensation correspond to the configurations with low augmentation levels and extra time delays and lags added. The correlation of pilot rating and pilot compensation generally agrees with data from Reference 5 and 9. This means that the amount of phase compensation at the bandwidth frequency required to meet the closed-loop performance criteria is a good measure of pilot acceptance of the configuration. The same values appear to be valid for fighter tasks as well as transport approach tasks as long as the appropriate bandwidth is chosen.

The Short Aft Tail configurations do not appear to correlate well with these criteria. Pilot ratings up to 10 were received for configurations which required only 55 degrees of phase compensation. The Extra-High q-augmented configuration required only 17 degrees of compensation but still

TABLE IX. PILOT COMPENSATION FOR CLOSED-LOOP θ/θ_c BANDWIDTH

ω_{BW}=1.5 rad/sec (90° Closed Loop Phase Lag)

$$Y_{P_\theta} = K_{P_\theta} e^{-.25s} \left(\frac{5s+1}{s}\right)(\tau_L + 1)$$

Configuration	LEVEL OF DELAY (T_1)								
	A			B			C		
	τ_L sec	Lead @ ω_{BW} $\tan^{-1} 1.5\,\tau_L$ deg	K_{P_θ} $\frac{\text{lb}}{\text{rad-sec}}$	τ_L sec	Lead @ ω_{BW} $\tan^{-1} 1.5\,\tau_L$ deg	K_{P_θ} $\frac{\text{lb}}{\text{rad-sec}}$	τ_L sec	Lead @ ω_{BW} $\tan^{-1} 1.5\,\tau_L$ deg	K_{P_θ} $\frac{\text{lb}}{\text{rad-sec}}$
<u>Long Aft</u> Unaug.	1.33*	63	1.61				3.47	79	.68
Low α	1.33	63	1.40	2.00	72	1.02	2.70	76	.79
Med α	1.13	59	1.56	1.53	66	1.29	2.47	75	.81
High α	.97	55	1.65	1.33	63	1.35	2.00	72	.92
Ex-High α	.73	48	1.79						
High α, N_z/α = 3	.87	53	1.76						
High α, N_z/α = 2	.87	53	1.65						
Low q	6.67*	84	.96				6.67*	84	1.12
Med q	2.53	75	1.05	4.67	82	.62	10.0*	86	.30
High q	.80	50	1.42	1.03	57	1.26	1.33	63	1.04
<u>Canard</u> Unaug.	1.33	63	1.55						
Low α	1.23	62	1.48	1.87	70	1.07	2.67	76	.78
Med α	1.15	60	1.51	1.53	66	1.27	2.40	74	.83
High α	1.00	56	1.57	1.47	66	1.19	2.00	72	.91
Ex-High α	.83	51	1.48						

*Performance criteria of maximum 3 dB resonance could not be achieved.

TABLE IX. PILOT COMPENSATION FOR CLOSED-LOOP θ/θ_c BANDWIDTH (CONT'D)

ω_{BW}=1.5 rad/sec (90^o Closed Loop Phase Lag)

$$Y_{P_\theta} = K_{P_\theta} e^{-.25s} \left(\frac{5s+1}{s}\right)(\tau_L + 1)$$

Configuration	LEVEL OF DELAY (T_1)								
	A			B			C		
	τ_L sec	Lead @ ω_{BW} $tan^{-1}1.5\,\tau_L$ deg	K_{P_θ} lb/rad-sec	τ_L sec	Lead @ ω_{BW} $tan^{-1}1.5\,\tau_L$ deg	K_{P_θ} lb/rad-sec	τ_L sec	Lead @ ω_{BW} $tan^{-1}1.5\,\tau_L$ deg	K_{P_θ} lb/rad-sec
Canard, cont'd									
High q	.73	48	1.45						
Short Aft									
Med α	1.13	59	1.61	1.60	67	1.26			
High α	.93	54	1.77	1.33	63	1.40			
Med q	4.67	82	.73						
High q	.97	55	1.32				(3.67	80	.44)**
Ex-High q	.21	17	1.26						

**T_1 = .35 (shuttle lag/delay)

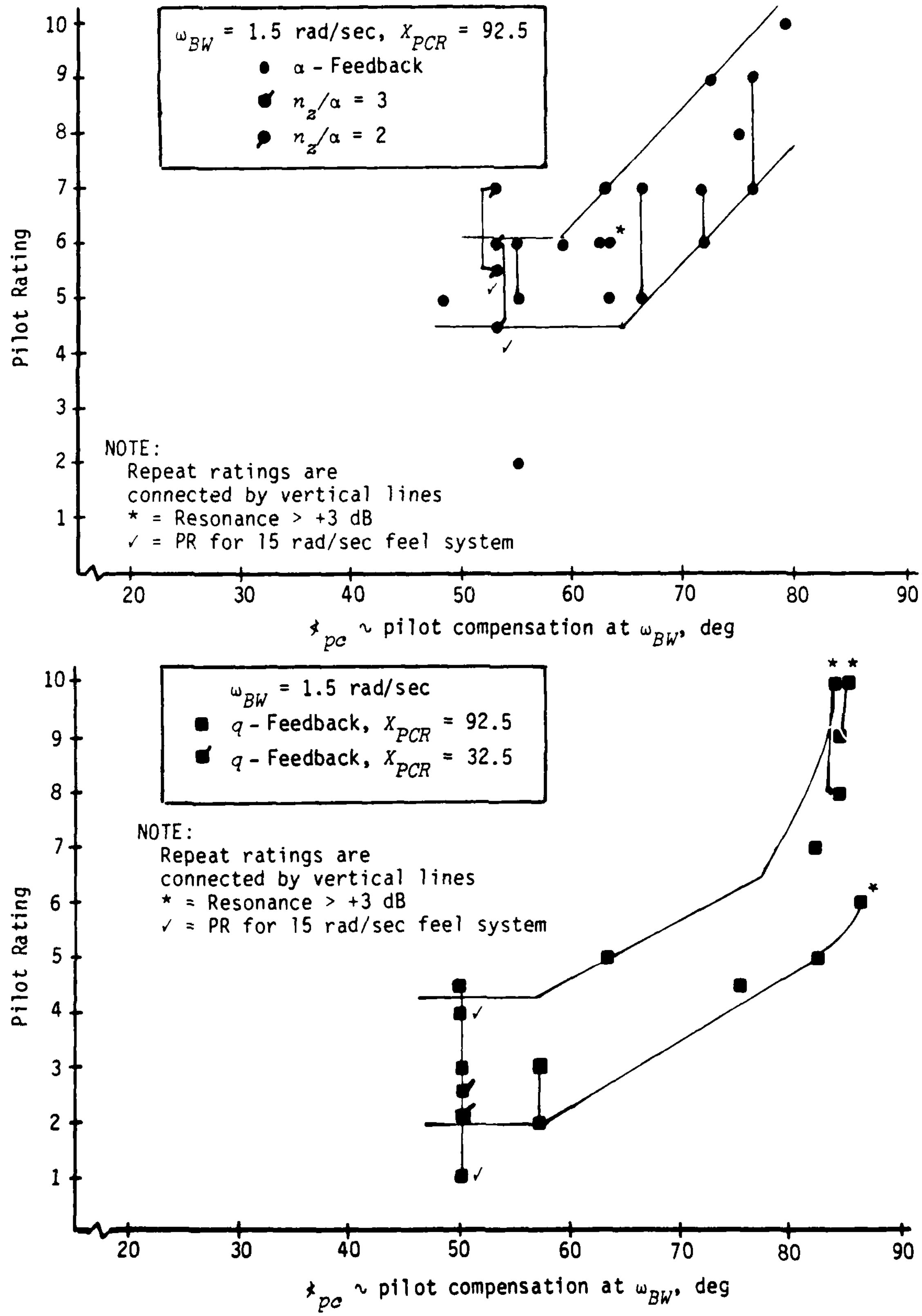


Figure 36. LONG AFT TAIL PILOT RATINGS VS PILOT LEAD COMPENSATION

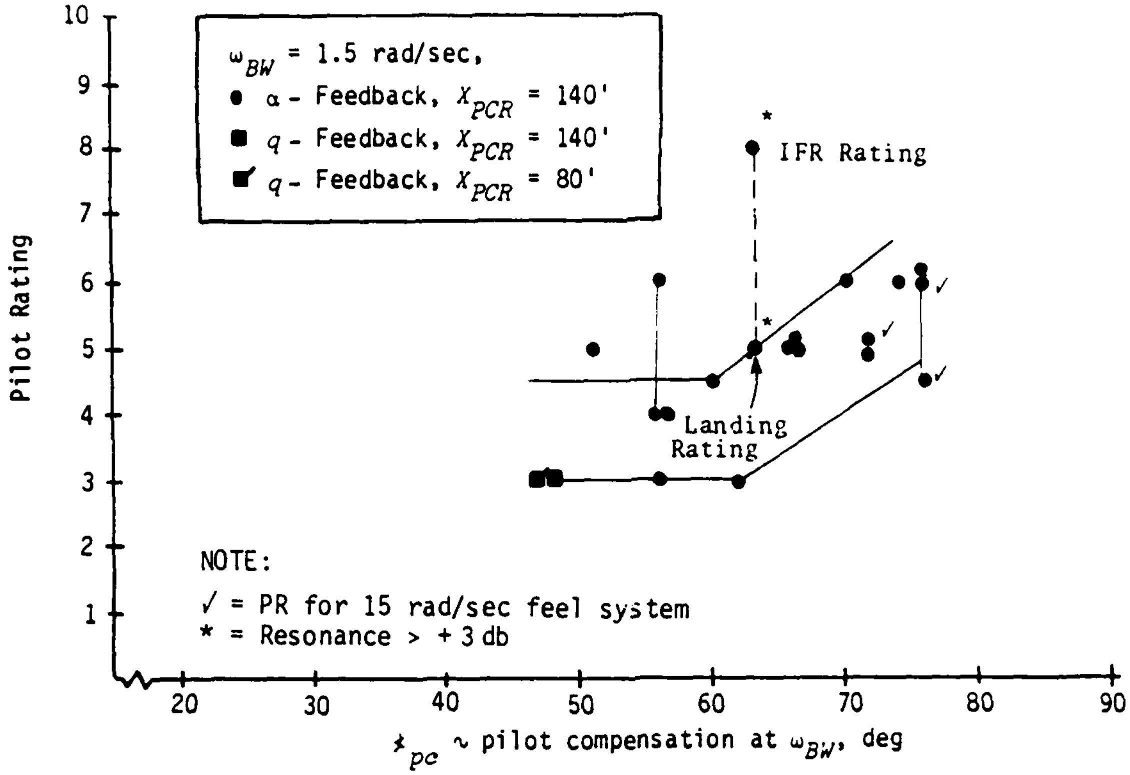


Figure 37. CANARD PILOT RATINGS VS PILOT LEAD COMPENSATION

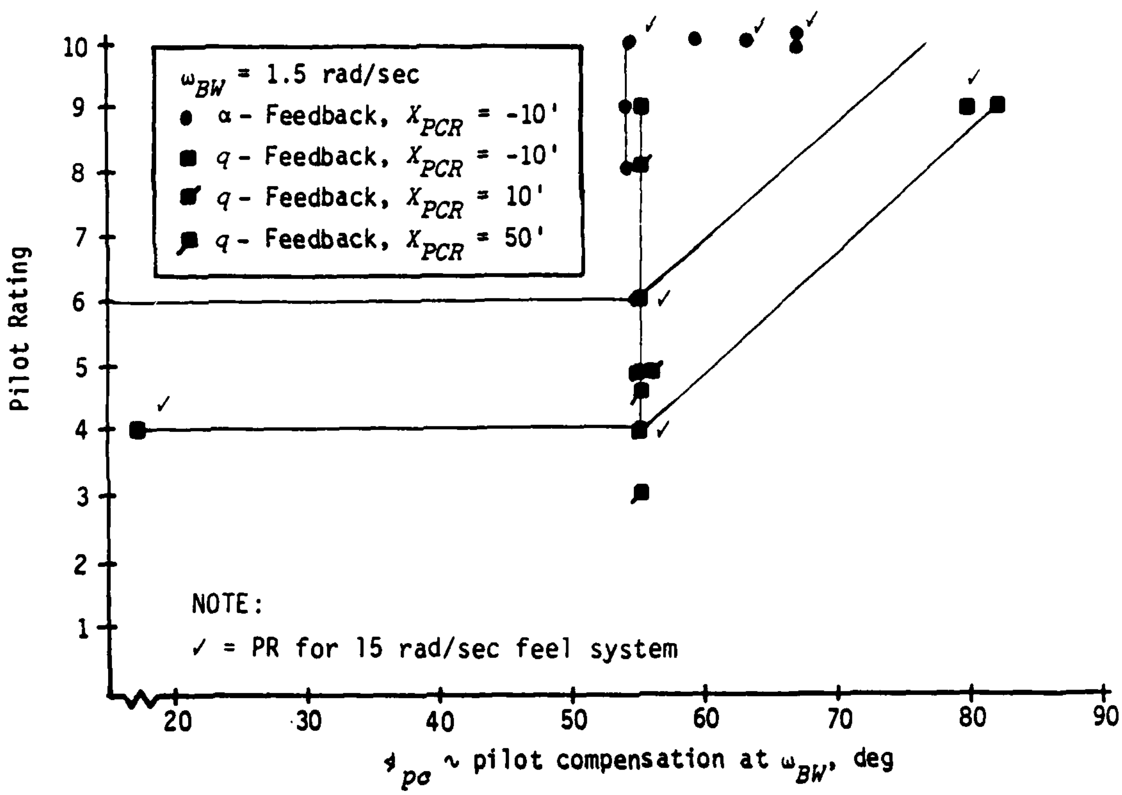


Figure 38. SHORT AFT TAIL PILOT RATINGS VS PILOT LEAD COMPENSATION

received a pilot rating of 4. This again points out the fact that the pilot uses more than just attitude in his control scheme. Normal acceleration, altitude rate, and altitude responses at the pilot position must also be important.

For both the Long Aft and Short Aft Tail configurations, the q-augmented configurations consistently received better ratings than the α-augmented ones even though the required pilot compensation was nearly the same. The attitude hold and no pitch force in turns features of the q-augmented configurations definitely improved these ratings over the comparable α-augmented configurations. The attitude hold feature rejected pitch disturbances due to ground effect where as the α-augmented configurations were disturbed by the pitching variation below 50 feet. The operation of the aircraft on the backside of the power required curve in conjunction with the slow thrust response also appears to put a limit on the best pilot ratings of approximately 3. Only rarely were pilot ratings of 2 or 1 received. The pilots downgraded otherwise good configurations due to the speed control problems. This again shows that characteristics other than closed-loop attitude control are affecting pilot ratings.

4.4 EFFECT OF BANDWIDTH ON ALLOWABLE TIME DELAY

From previous experiments dealing with higher-order systems and their effective time delays, there appears to be a general increase in the level of time delay acceptable as the task presented the pilot becomes less difficult. Reference 4 compiles much of this data and, in particular, shows the effect of time delay on pilot ratings for three degrees of task difficulty. Data from Reference 5 was obtained from air-to-air combat evaluations. Data from Reference 6 was obtained from fighter landing approach and actual touchdown evaluations. Data from reference 10 was obtained from fighter up-and-away and low-altitude waveoff approach evaluations. The closed-loop pitch attitude bandwidths which pilots were generally believed to be requiring in these experiments were 3.5 rad/sec, 2.5 rad/sec, and 1.5 rad/sec, respectively as the task became less critical and the pilot did not have to be as aggressive. Shown in Figure 39 are the bands of effective time delay t_1, calculated from the maximum slope

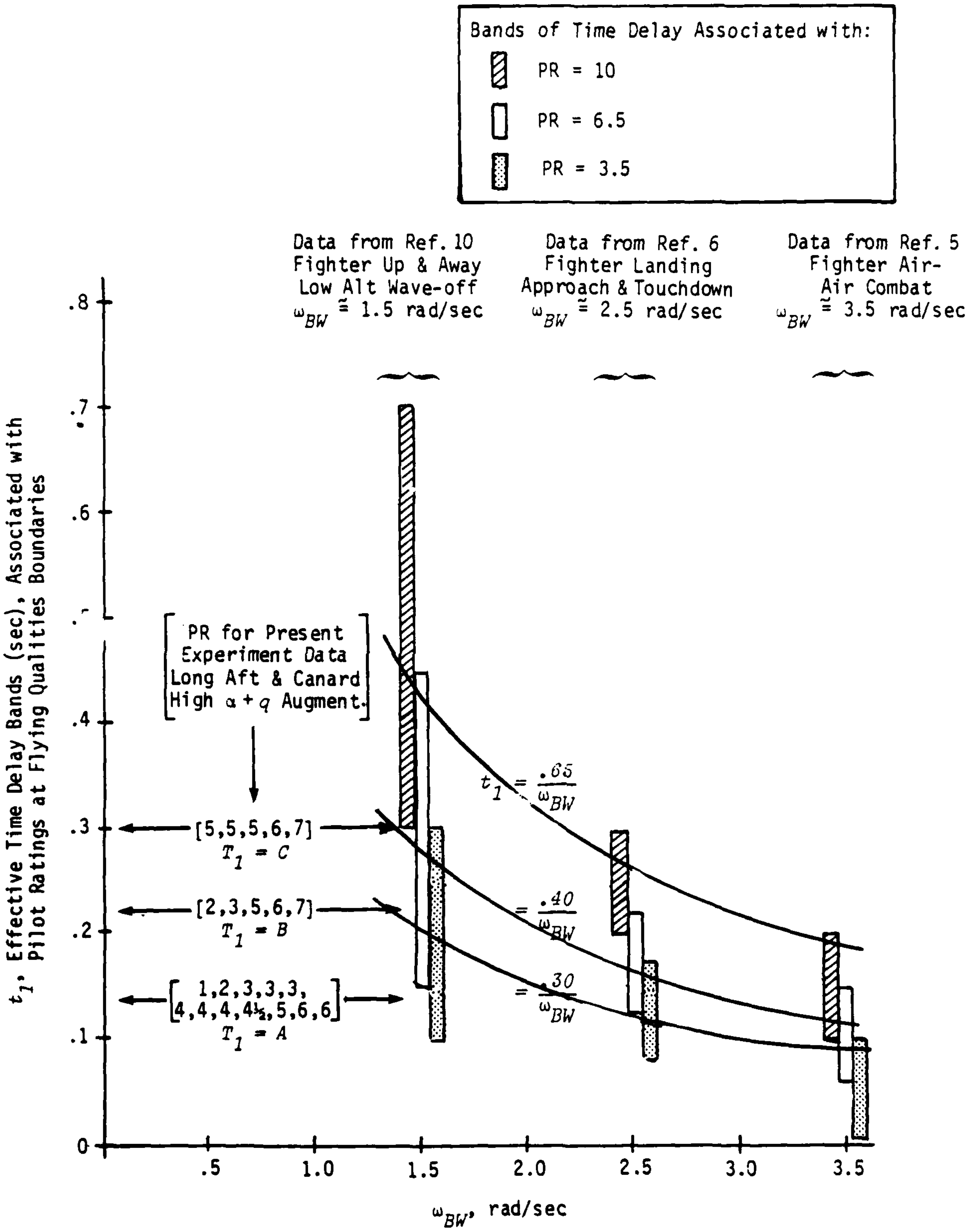


Figure 39. TIME DELAY BANDS ASSOCIATED WITH FLYING QUALITIES BOUNDARIES VS BANDWIDTH

intercept method, associated with the boundaries of flying qualities levels (pilot rating of 10, 6.5, 3.5) versus the bandwidth for the evaluation task. The data from which these bands were obtained are from configurations that were rated Level 1 with minimal time delay. It can easily be seen that the pilot becomes much more tolerant of, or less sensitive to, time delays as the tasks become less critical. The landing approach and simulated touchdown task of the present experiment with a large, slow-responding aircraft can be considered as having the same bandwidth requirements (1.5 rad/sec) as the fighter up-and-away and low altitude waveoff task of Reference 10. When the present experimental data for the Long Aft Tail and Canard High α plus q-augmented configurations are pointed out on Figure 39, it verifies the trend shown, i.e. large time delays become acceptable at low bandwidth and relatively little degradation in pilot rating results from the large variation of time delay used in the present experiment, compared to higher bandwidth tasks.

A functional relationship was determined between the average tolerable effective time delay and bandwidth for the task for pilot ratings of 10, 6.5, and 3.5. In the relationships derived, the allowable effective time delay, t_1, was inversely proportional to the bandwidth of the task for the various flying qualities levels:

Average

$$@\ PR = 10 \qquad t_1 = \frac{.65}{\omega_{BW}}$$

$$@\ PR = 6.5 \qquad t_1 = \frac{.4}{\omega_{BW}}$$

$$@\ PR = 3.5 \qquad t_1 = \frac{.3}{\omega_{BW}}$$

These relationships are plotted on Figures 39 and 40, along with the data from the Long Aft Tail and Canard, High α plus q-augmented configurations. For the data from the present experiment, the average pilot ratings increased from approximately 3.5 to 6 as the effective time delay increased from .14 to .3. This tends to support the relationships shown at ω_{BW} = 1.5 rad/sec.

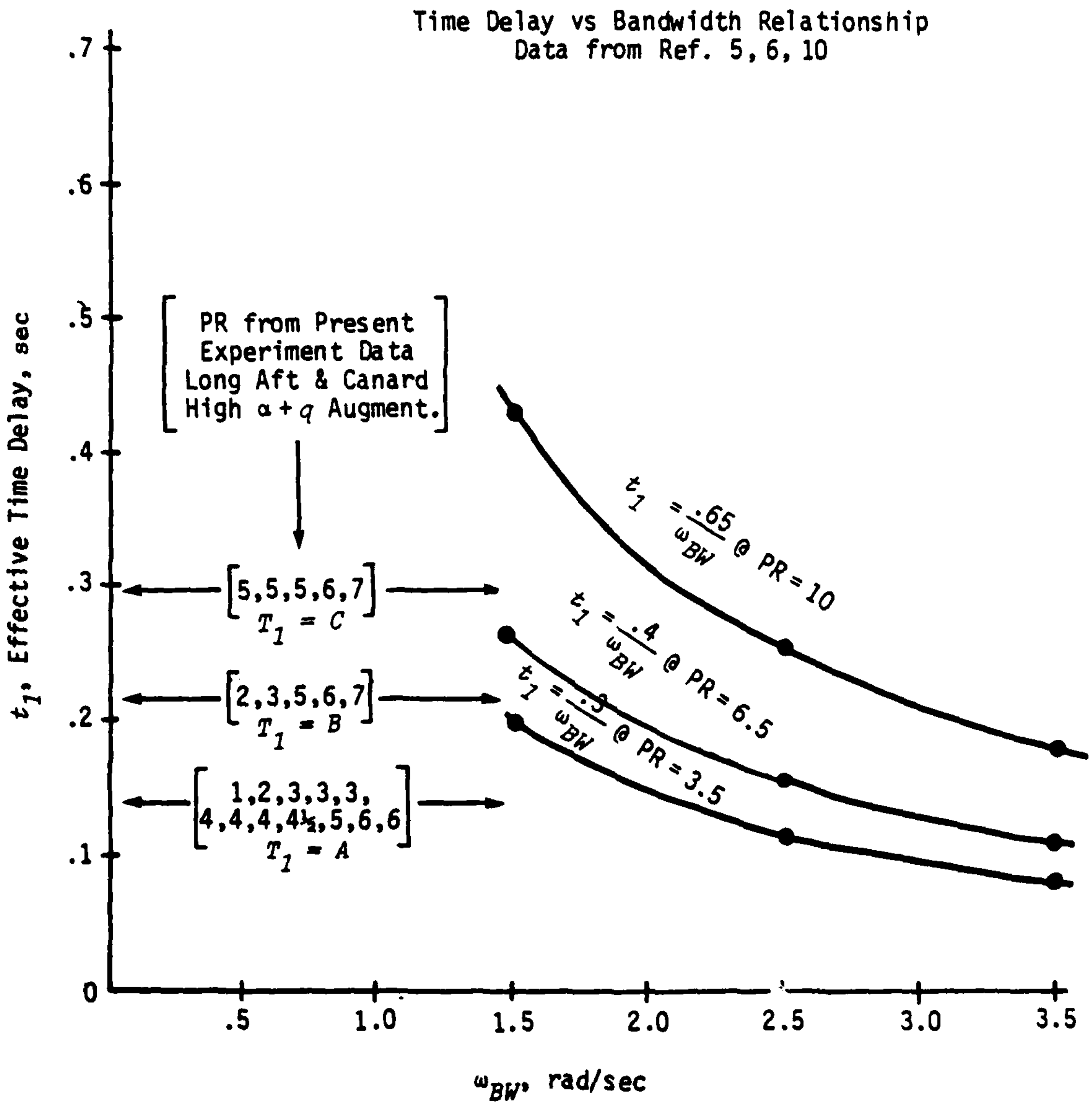
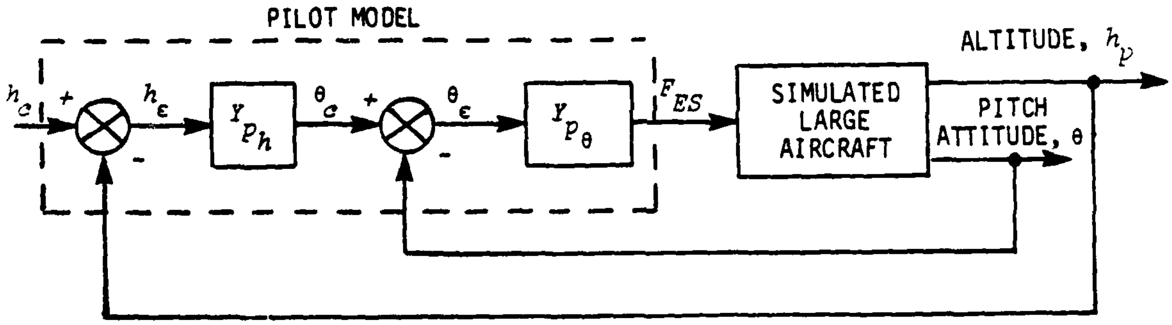


Figure 40. TIME DELAY VS BANDWIDTH @ PR = 10, 6.5, 3.5

4.5 MULTI-LOOP ANALYSIS

In order to better understand the evaluations of configurations with varying pilot position versus instantaneous pitch center of rotation with all other characteristics constant, a multi-loop analysis was performed. The model of the control structure is shown in Figure 41. There is an inner pitch attitude control loop with an outer altitude control loop in series. In the outer loop, the pilot is controlling the altitude he sees at the pilot station. The inner-loop pilot gain (K_{p_θ}) and lead (τ_L) were fixed at the values obtained in the pitch attitude closed-loop analysis (Section 4.3.2) where a bandwidth of 1.5 rad/sec was achieved. The pilot model for the outer loop was a pure gain, K_{p_h}, regulating the perceived altitude error, h_ε, at the pilot's position. The lead term in the inner loop ($\tau_L s+1$) effectively gives some lead in the altitude loop also.



$$Y_{p_\theta} = K_{p_\theta} e^{-.25s}\left(\frac{5s+1}{s}\right)(\tau_L s + 1), \text{ pound/rad}$$

$$Y_{p_h} = K_{p_h}, \text{ rad/ft}$$

Figure 41. CONTROL STRUCTURE FOR MULTI-LOOP ANALYSIS

Configurations analyzed included the Short Aft Tail, High q-augmented, delay $T_1 = A$, with pilot position $X_{MP} = 50$, 70, 110 feet or pilot position with respect to the center of rotation (X_{PCR}) of 10 feet aft, 10 feet forward, and 50 feet forward, respectively. Added to these configurations were the Long Aft Tail and Canard, High q-augmented configurations which have similar dynamics as the Short Aft Tail configurations. The pilot positions of these extra configurations were $X_{PCR} = 92.5$ feet forward and 140 feet forward of the center of rotation.

In addition the Short Aft Tail, High q-augmented configuration with extra delay, $T_1 = .35$ (equivalent to the shuttle's lag/delay) and the Extra-High q-augmented configuration were analyzed.

The analysis is based on the transfer functions in Appendix I which are evaluated at the nominal trim speed. Complete transfer functions were used without simplification or approximation. The time delays were treated in $e^{-\tau s}$ form. The computer program developed in Reference 12 was used to calculate root loci, and Nichols diagrams were used to determine closed-loop bandwidth. It should be noted that all of the configurations have a low-frequency factor in the numerator of the altitude-elevator transfer function that is in the right half plane as a result of being on the "backside." The analysis performed considered multiple feedback to a single controller, the elevator. This loop closure results in a low-frequency pole of the closed-loop system being driven toward the low-frequency zero of the altitude-elevator transfer function, and in all of these configurations this zero was unstable, very slightly.

Configuration	Zero Location	Closed-Loop Pole
Short Aft	+.0037	+.0036 for $K_{P_h} = .010$
Long Aft	+.0030	+.0030 for $K_{P_h} = .014$
Canard	+.0023	+.0022 for $K_{P_h} = .014$

In order to stabilize this closed-loop pole, it would be necessary to close a low-gain feedback loop of airspeed to the throttle. This loop closure was not included in the analysis, and the results described in the following paragraphs must be viewed with that fact in mind.

Although the closed-loop system transfer function was 11th order over 15th order and included time delay, the root locus analysis will be discussed in terms of the dominant set of complex roots of the closed-loop altitude-stick force dynamic system.

The results are presented in two sets of figures and Table X. Figures 42 through 49 show the altitude error mode root locus as a function of the pilot altitude gain, K_{P_h}. Figures 50 through 57 are Nichols plots of the open-loop h/h_{ε} transfer function (with inner θ loop closed), on which the closed-loop 3 dB and 9 dB resonance levels, closed-loop 90° phase lag, and closed-loop 3 dB droop lines are drawn. First the open-loop frequency response of $Y_{P_h}(h_p/\theta_c)$ was plotted, normalized to 0 dB amplitude at a frequency of 1 rad/sec. Then on these plots a partial grid of closed-loop amplitude and phase was placed in a position to show the closed-loop bandwidth (at -90° phase) for 3 dB resonance. The displacement of this grid from being centered at 0 dB is the gain increment required to normalize the open-loop frequency response and is indirectly related to the value of K_{P_h} printed on the chart. This graphical technique was used to illustrate the simplicity of Nichols diagrams for performing dynamic analysis when only the loop gain is being varied.

From the root loci (Figures 42 through 44) for the Short Aft Tail configurations, it can be seen that the altitude mode goes unstable at increasingly higher gain and higher frequency as the pilot position is moved forward. The potential closed-loop bandwidth is thus higher at the more forward pilot locations. Low altitude-loop bandwidth correlates highly with the occurrence of PIO's near touchdown. The Long Aft Tail and Canard configurations do not go unstable at all (Figures 45 and 46) in this mode.

The Nichols plots for these configurations (Figures 50 through 54) show that the highest achievable bandwidth for the altitude control loop increased from .43 rad/sec to 2.30 rad/sec as the pilot position was moved from 10 feet aft to 140 feet forward of the center of rotation. Note the large increase in bandwidth going from the Long Aft Tail to Canard configuration. It should be noted that the pilot lead for the inner loop (τ_L) was slightly lower for the Long Aft Tail (.80 sec) and Canard (.73 sec) configurations compared to the Short Aft Tail (.97 sec) configuration. The lower inner-loop lead time constant results in an outer altitude-loop bandwidth that is lower than would be possible with a .97 sec lead.

TABLE X. RESULTS OF MULTI-LOOP ANALYSIS

Configuration	X_{PCR}, ft Center of Rotation to Pilot	Inner Pitch Loop Pilot Model (Achieves $\omega_{BW_\theta} = 1.5$ rad/sec)	Outer Altitude Loop		Pilot Rating	PIO Rating
			Gain, K_{P_h} (rad/ft) for ω_{BW_h}	Highest Bandwidth Achievable ω_{BW_h}, rad/sec		
Short Aft Tail, High q $X_{MP} = 50'$, $T_1 = A$	-10	$1.32e^{-.25s}(.97s+1) \cdot \left(\frac{5s+1}{s}\right)$	.0016	.43	9,5,6,4	4,3,3,2
Short Aft Tail, High q $X_{MP} = 70'$, $T_1 = A$	10	$1.32e^{-.25s}(.97s+1) \cdot \left(\frac{5s+1}{s}\right)$	.0017	.45	5	1
Short Aft Tail, High q $X_{MP} = 110'$, $T_1 = A$	50	$1.32e^{-.25s}(.97s+1) \cdot \left(\frac{5s+1}{s}\right)$	.0020	.48	4.5,3	1,1
Long Aft Tail, High q $X_{MP} = 110'$, $T_1 = A$	92.5	$1.42e^{-.25s}(.80s+1) \cdot \left(\frac{5s+1}{s}\right)$	.0027	.55	3,4.5, 4,1	1,2,3 1
Canard, High q $X_{MP} = 110'$, $T_1 = A$	140.0	$1.45e^{-.25s}(.73s+1) \cdot \left(\frac{5s+1}{s}\right)$	.0028	2.30	3	1
Short Aft Tail, High $X_{MP} = 50'$, $T_1 = .35$	-10	$.44e^{-.25s}(3.67s+1) \cdot \left(\frac{5s+1}{s}\right)$	.0014	.33	9	4
Short Aft Tail, Ex-High q $X_{MP} = 50'$, $T_1 = A$	-10	$1.26e^{-.25s}(.21s+1) \cdot \left(\frac{5s+1}{s}\right)$	.0012	.38	4	2
Short Aft Tail, Ex-High q $X_{MP} = 50'$, $T_1 = A$ includes altitude-loop lead	-10	$1.26e^{-.25s}(.21s+1) \cdot \left(\frac{5s+1}{s}\right)$	.0023(.63 +1)	.50	4	2

Inner Loop:

$$Y_{p_\theta} = (1.318)e^{-.25s}(.37s + 1)\left(\frac{5s+1}{s}\right)$$

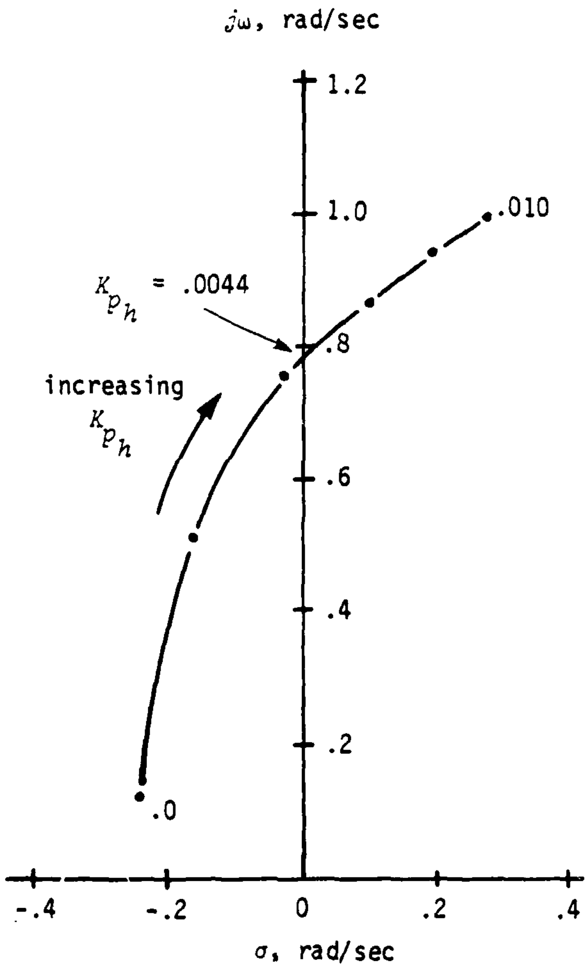


Figure 42. ALTITUDE LOOP ROOT LOCUS VS. K_{p_h} (RAD/FT)
SHORT AFT TAIL, HIGH q FEEDBACK, DELAY = A
X_{MP} = 50', X_{PCR} = -10'

Inner Loop:

$$Y_{p_\theta} = (1.318)e^{-.25s}(.97s+1)\left(\frac{5s+1}{s}\right)$$

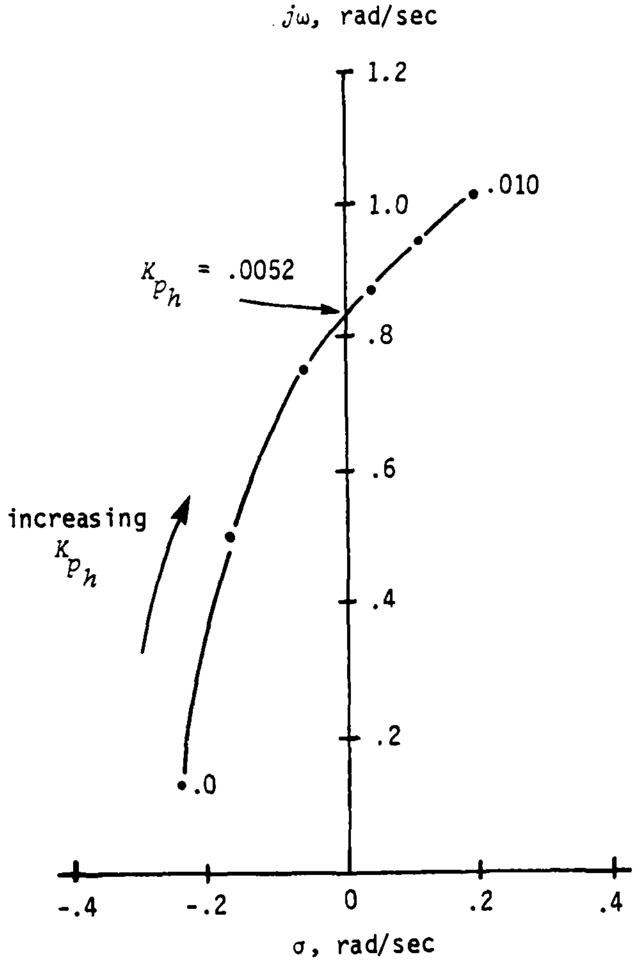


Figure 43. ALTITUDE LOOP ROOT LOCUS VS. K_{p_h} (RAD/FT)
SHORT AFT TAIL, HIGH q FEEDBACK, DELAY = A
X_{MP} = 70', X_{PCR} = 10'

Inner Loop:

$$Y_{p_\theta} = (1.318)e^{-.25s}(.97\,s + 1)\left(\frac{5s+1}{s}\right)$$

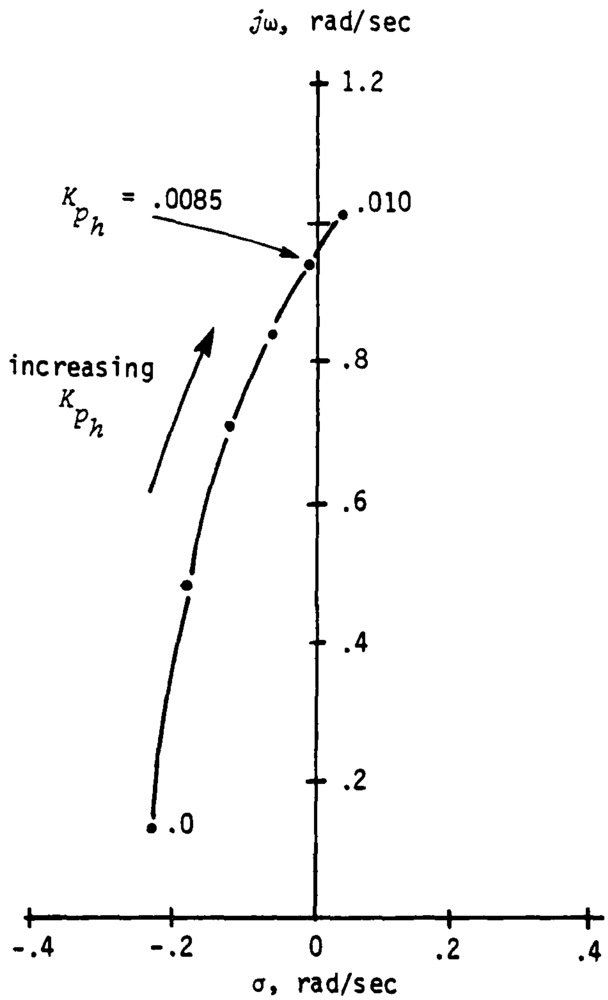


Figure 44. ALTITUDE LOOP ROOT LOCUS VS. K_{p_h} (RAD/FT)

SHORT AFT TAIL, HIGH q FEEDBACK, DELAY = A

X_{MP} = 110', X_{PCR} = 50'

Inner Loop:

$$Y_{p_\theta} = (1.418)e^{-.25s}(.80\,s+1)\left(\frac{5s+1}{s}\right)$$

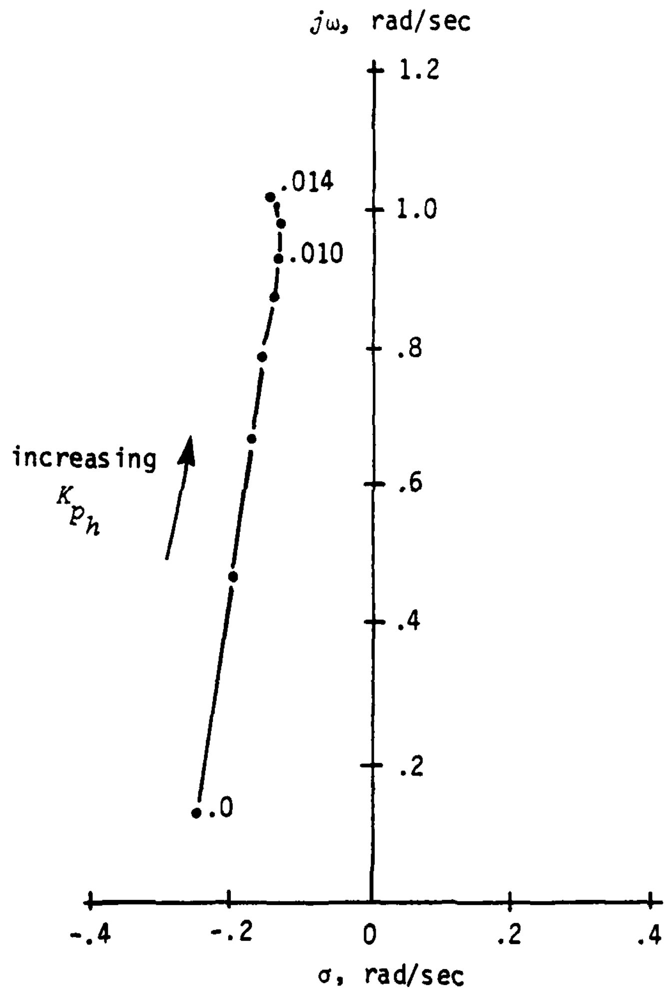


Figure 45. ALTITUDE LOOP ROOT LOCUS VS. K_{p_h} (RAD/FT)
LONG AFT TAIL, HIGH q FEEDBACK, DELAY = A
X_{MP} = 110', X_{PCR} = 92.5'

Inner Loop:

$$Y_{p_\theta} = (1.449)e^{-.25s}(.73\,s+1)\left(\frac{5s+1}{s}\right)$$

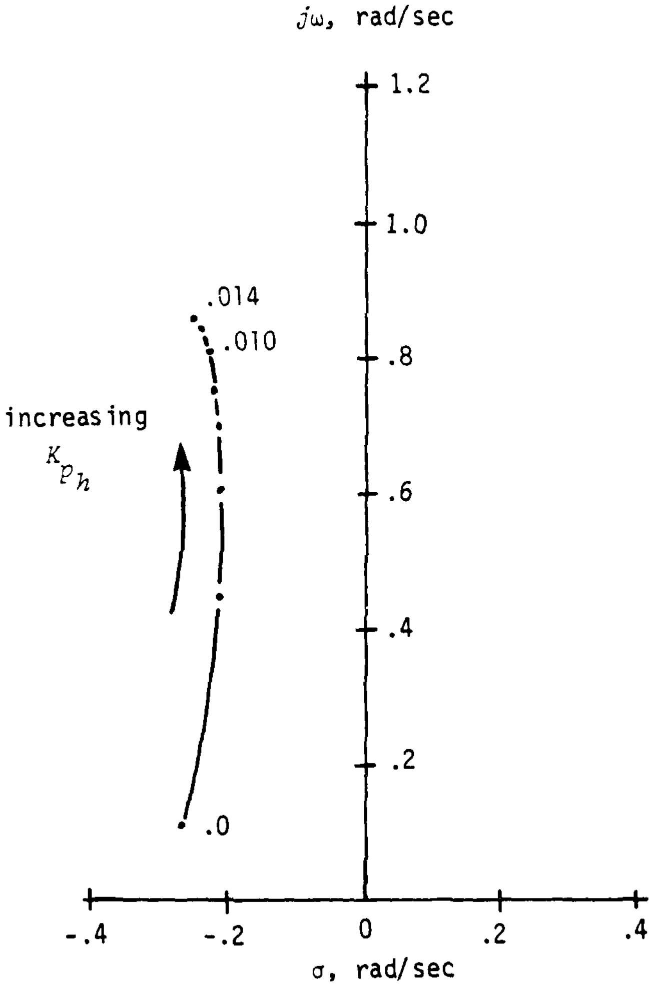


Figure 46. ALTITUDE LOOP ROOT LOCUS VS. K_{p_h} (RAD/FT)
CANARD, HIGH q FEEDBACK, DELAY = A
X_{MP} = 110', X_{PCR} = 140'

Inner Loop:

$$Y_{p_\theta} = (.435)e^{-.25s}(3.67\,s + 1)\left(\frac{5s+1}{s}\right)$$

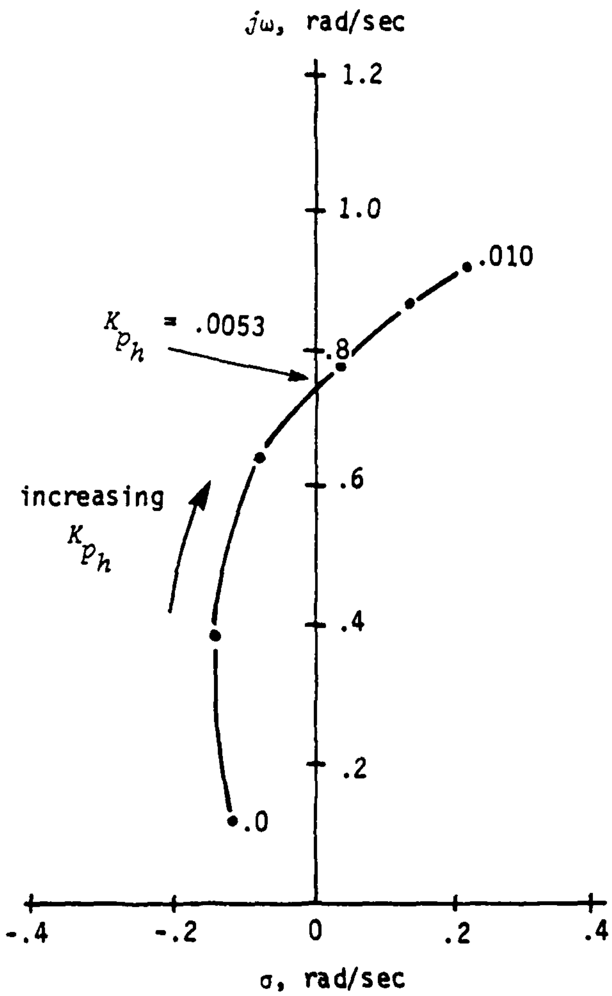


Figure 47. ALTITUDE LOOP ROOT LOCUS VS. K_{p_h} (RAD/FT)
SHORT AFT TAIL, HIGH q FEEDBACK, DELAY = .35
X_{MP} = 50', X_{PCR} = -10'

Inner Loop:

$$Y_{p_\theta} = (1.26)e^{-.25s}(.213\,s + 1)\left(\frac{5s+1}{s}\right)$$

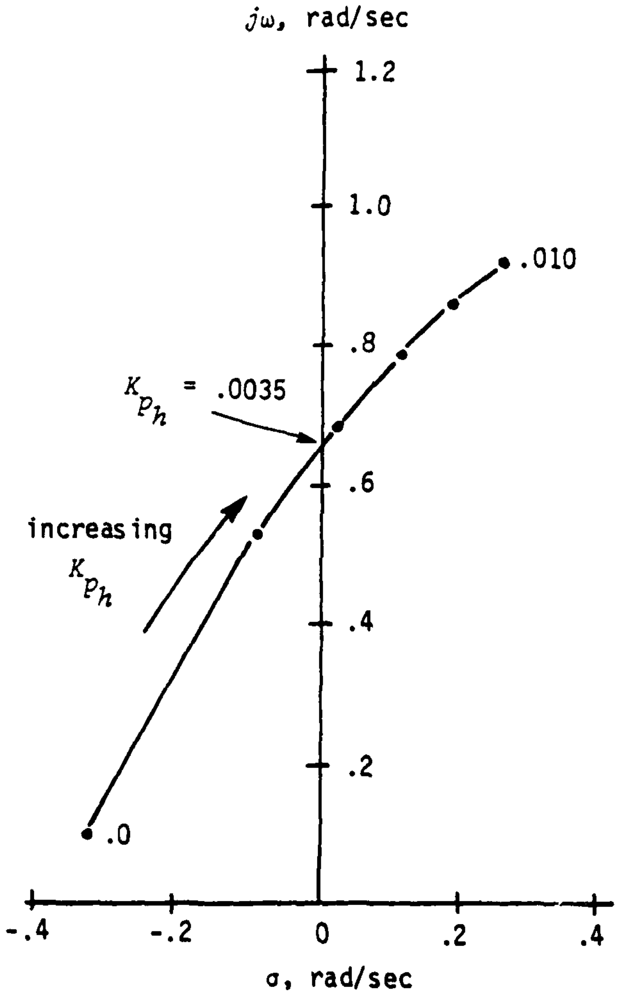


Figure 48. ALTITUDE LOOP ROOT LOCUS VS. K_{p_h} (RAD/FT)
SHORT AFT TAIL, EXTRA-HIGH q FEEDBACK, DELAY = A
X_{MP} = 50', X_{PCR} = -10'

Inner Loop:

$$Y_{p_\theta} = (1.26)e^{-.25s}(.213\,s + 1)\left(\frac{5s+1}{s}\right)$$

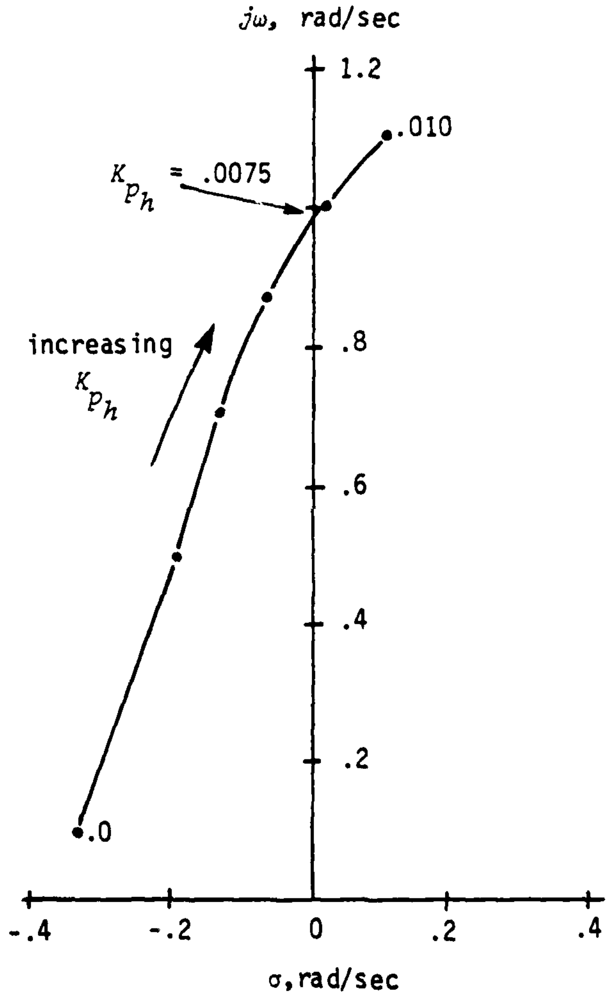
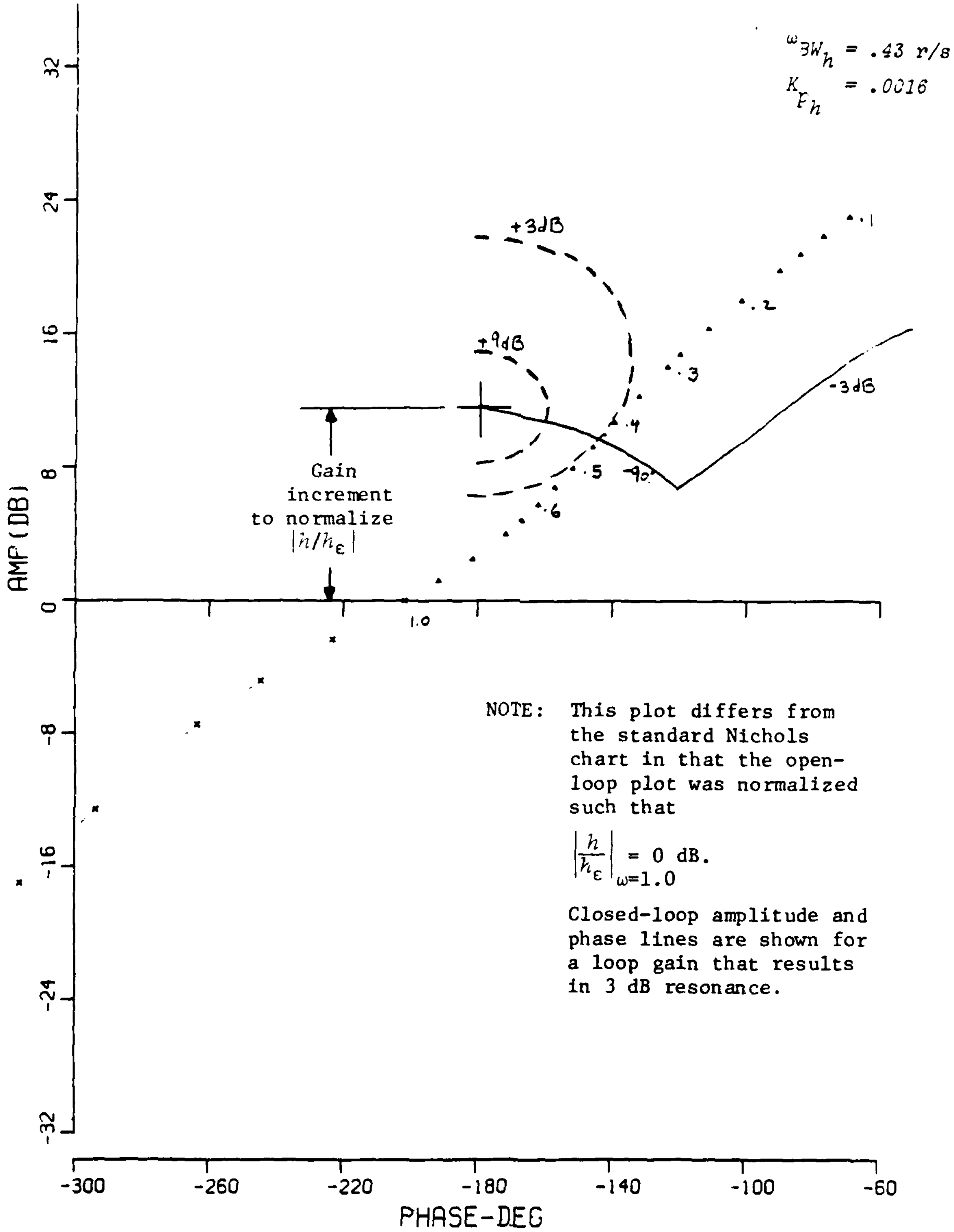


Figure 49. ALTITUDE LOOP ROOT LOCUS VS. K_{p_h} (RAD/FT)

WITH LEAD (.63 s + 1) IN h - COMMAND PATH
SHORT AFT TAIL, EXTRA-HIGH q FEEDBACK, DELAY = A

X_{MP} = 50', X_{PCR} = -10'



6 MAY 1981 #NNNN1 - S-9 TQ=1..KQ=2.51 HI).XP=50 .DEL=A .MULT-LOOP

Figure 50. SHORT AFT TAIL, HIGH q, X_{MP} = 50', T_1 = A, h/h_ε NICHOLS PLOT

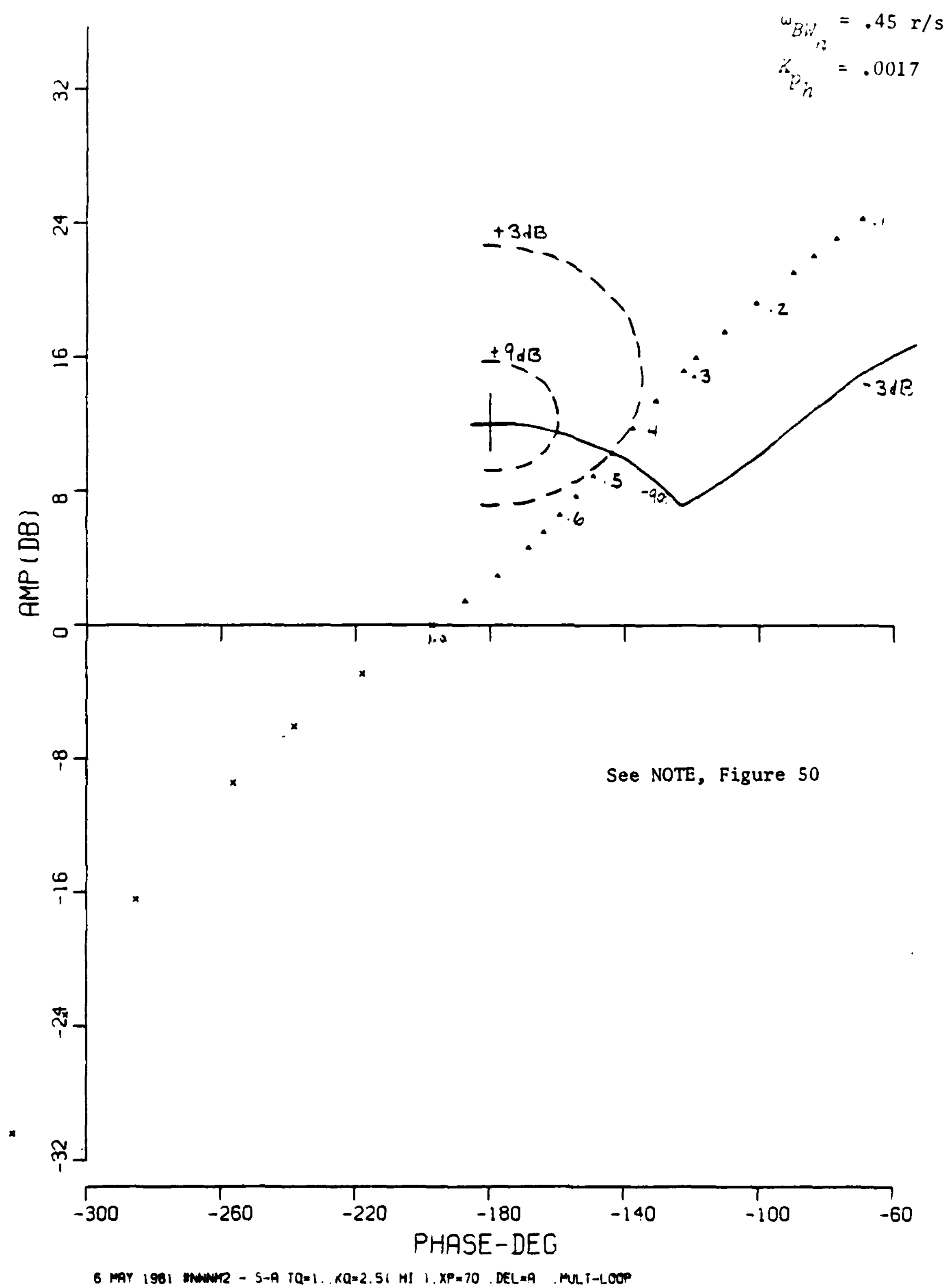


Figure 51. SHORT AFT TAIL, HIGH q, X_{MP} = 70', $T_1 = A$, h/h_ε NICHOLS PLOT

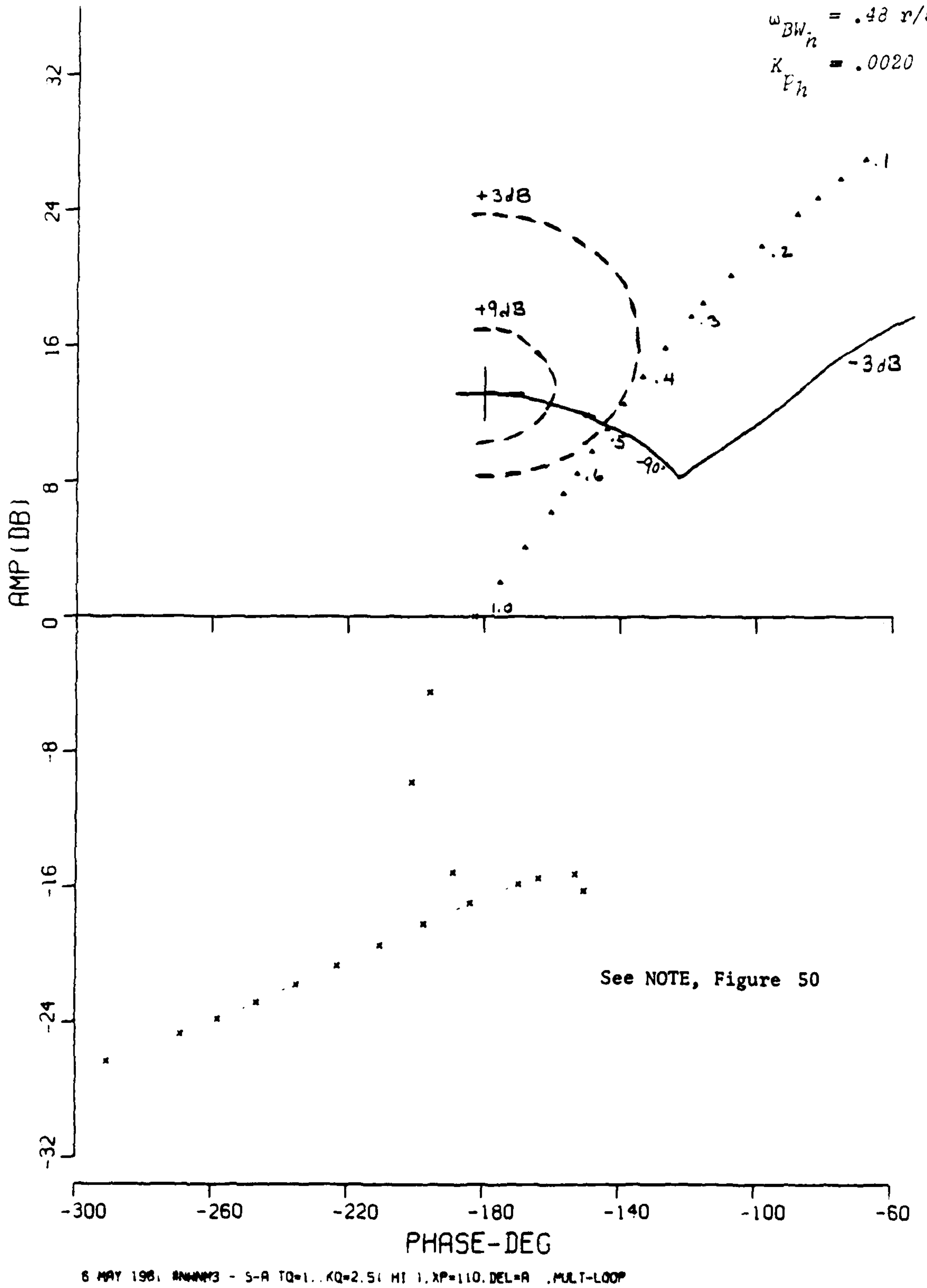
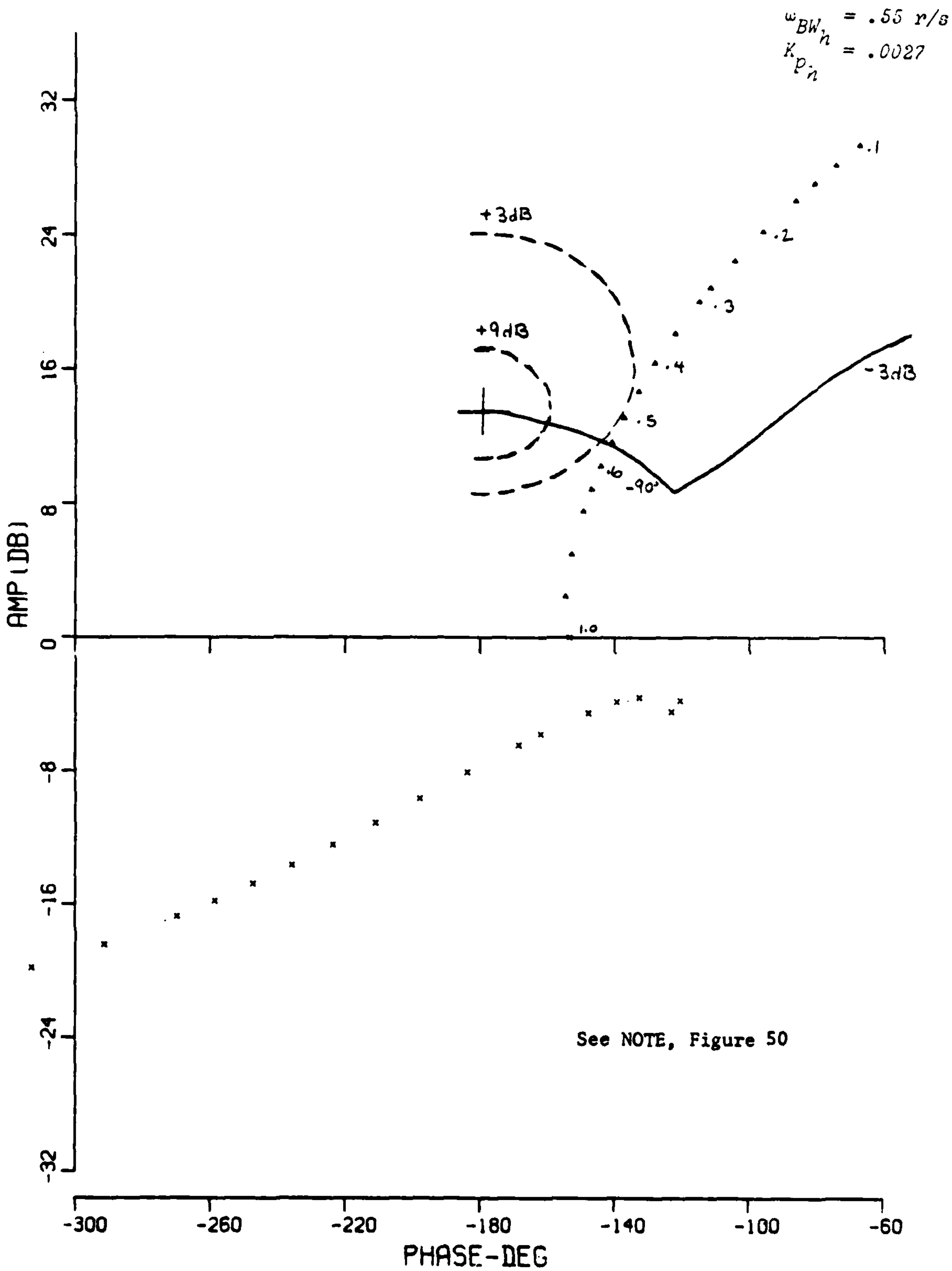


Figure 52. SHORT AFT TAIL, HIGH q, X_{MP} = 110', T_1 = A, h/h_ε NICHOLS PLOT



15 MAY 1981 ...MULTL-LONG TQ=1. .KQ=2. /3(HI).XP=... DEL=A . .MULT-LOOP

Figure 53. LONG AFT TAIL, HIGH q, X_{MP} = 110', T_1 = A, h/h_ε NICHOLS PLOT

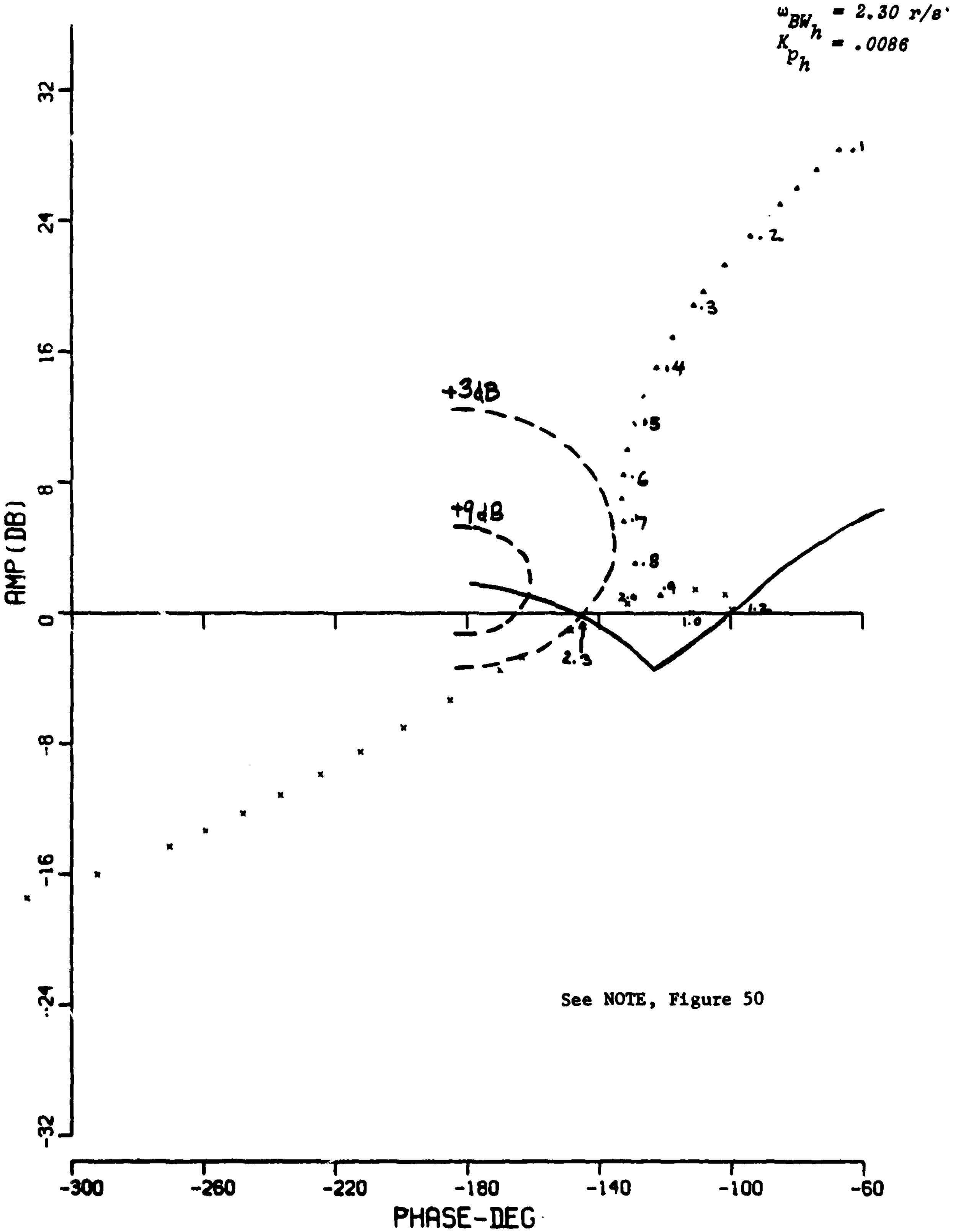


Figure 54. CANARD, HIGH q, X_{mp} = 110', T_1 = A, h/h_ε HICHOLS PLOT

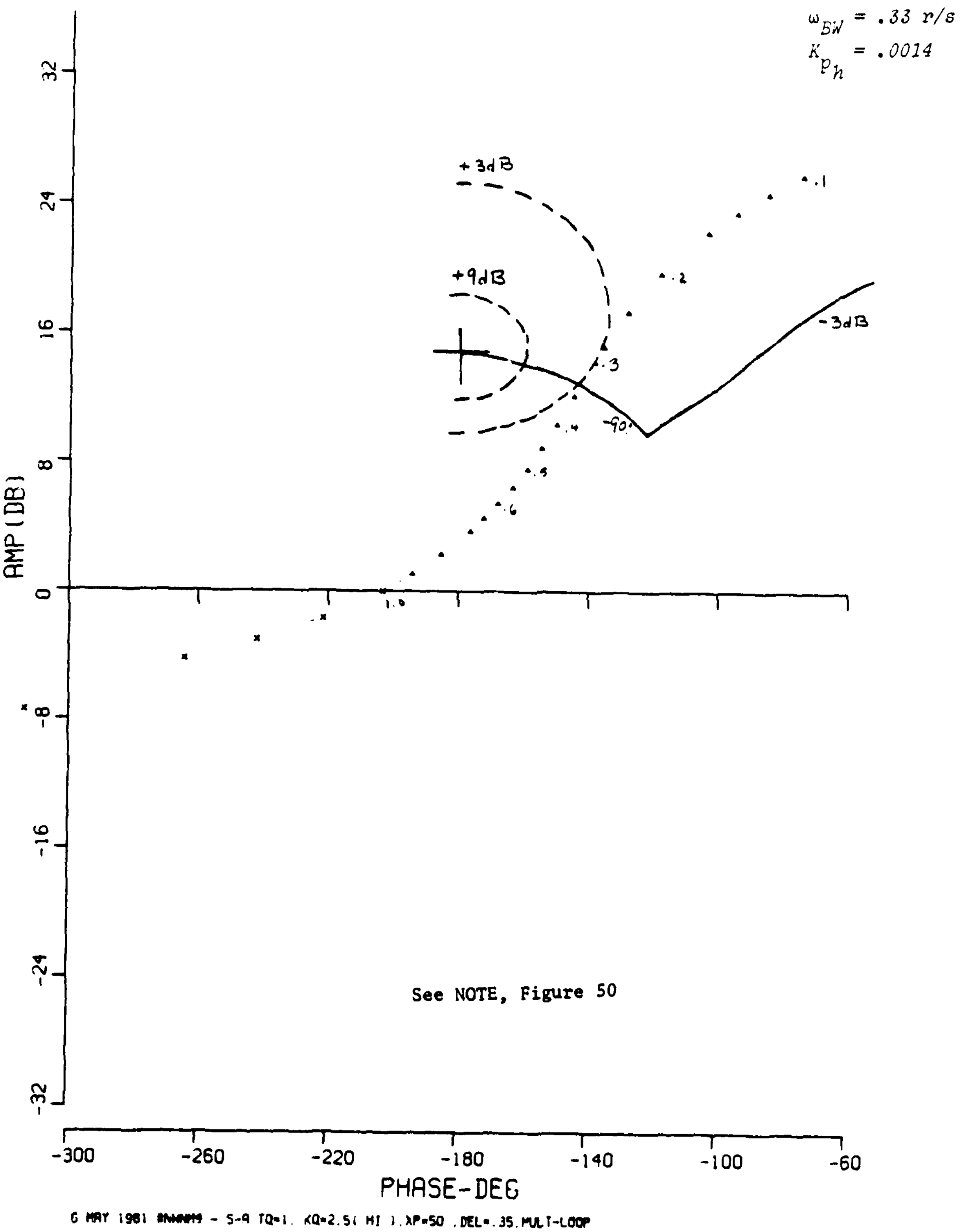


Figure 55. SHORT AFT TAIL, HIGH q, X_{MP} = 50', T_1 = .35, h/h_ε NICHOLS PLOT

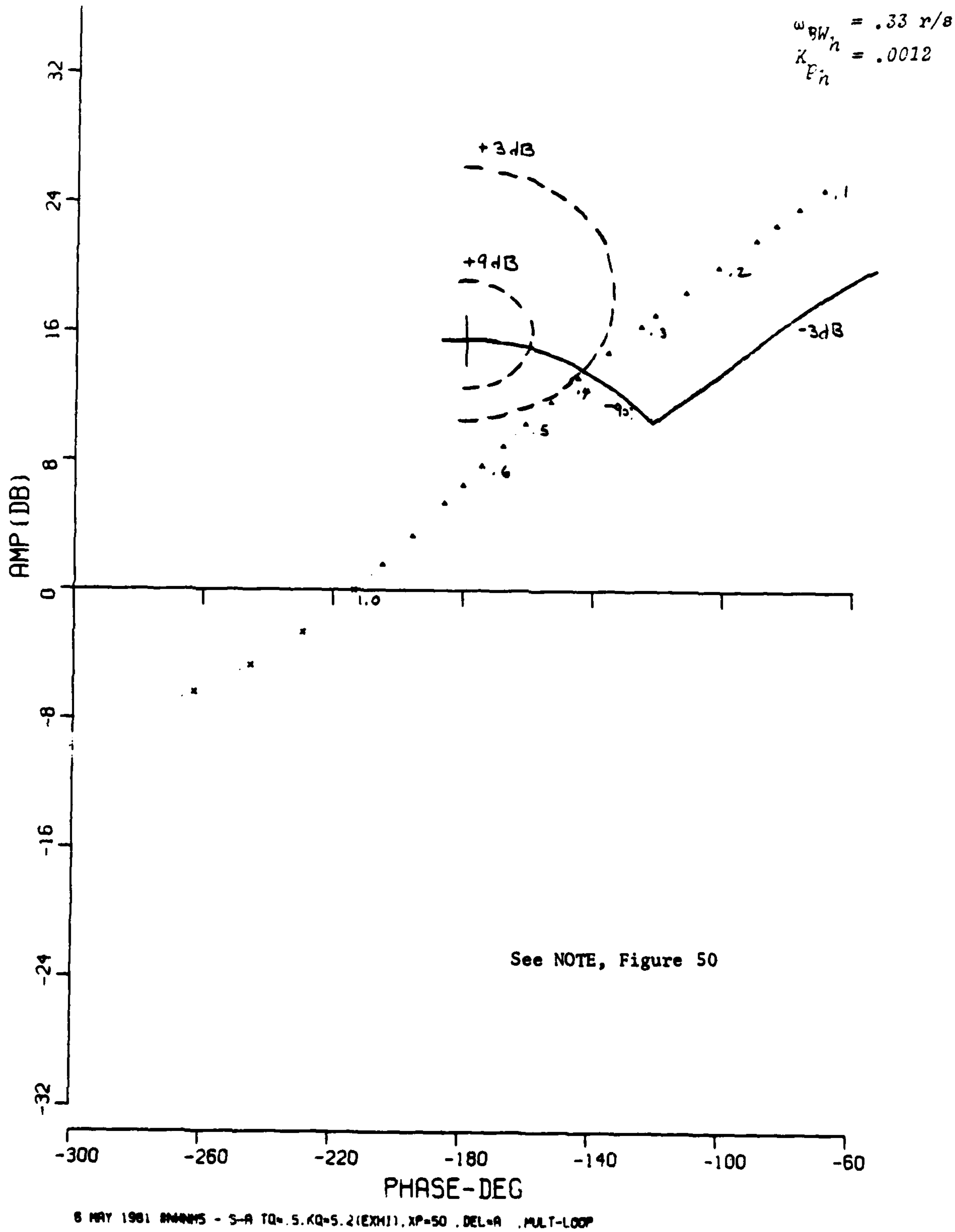


Figure 56. SHORT AFT TAIL, EX-HIGH q, X_{MP} = 50', T_1 = A, h/h_ε NICHOLS PLOT

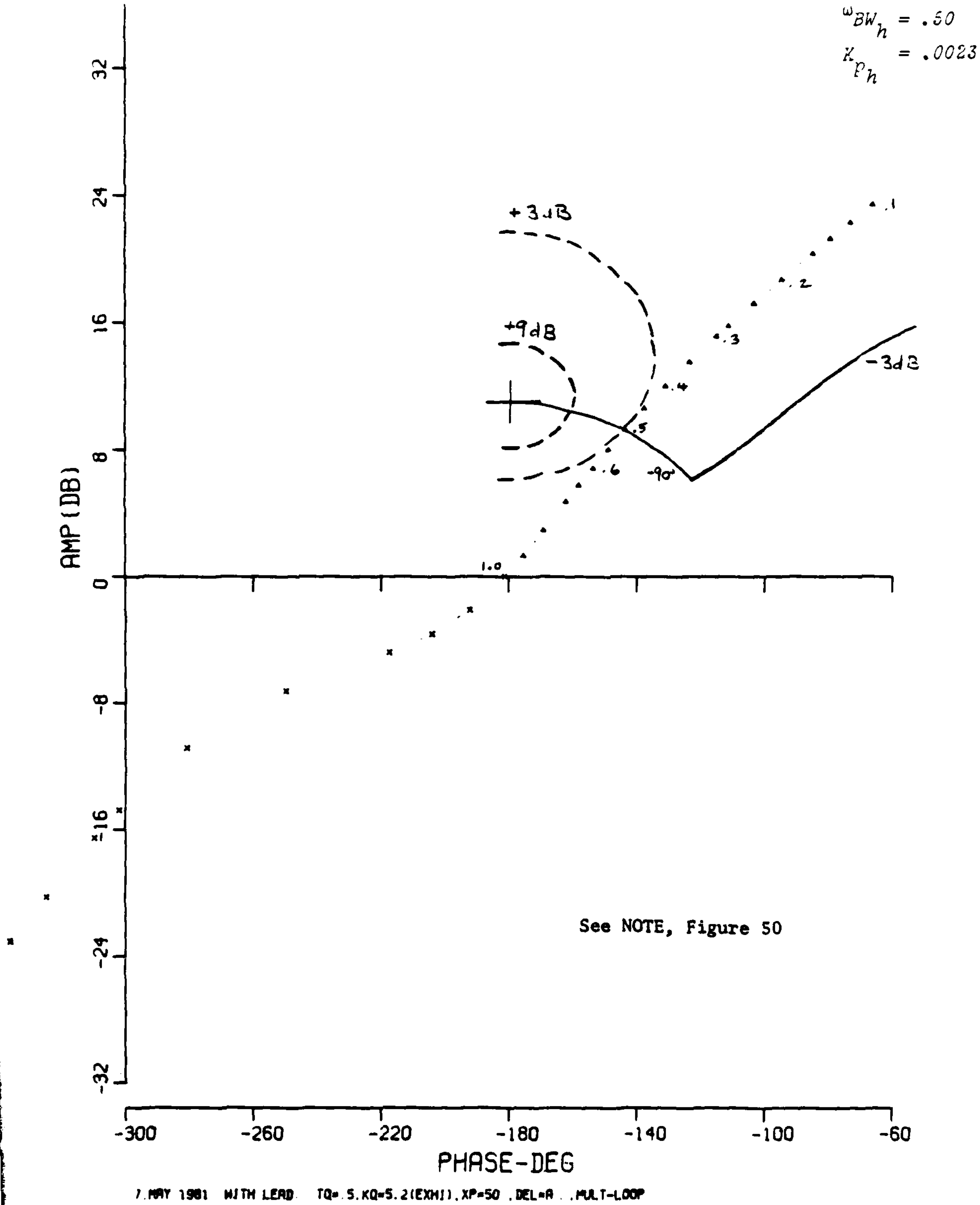


Figure 57. SHORT AFT TAIL, EX-HIGH q, X_{MP} = 50', T_1 = A, WITH (.63s+1) LEAD IN ALTITUDE CONTROL, h/h_ε NICHOLS PLOT

The analysis of the Short Aft Tail configuration with higher shuttle effective time delay (T_1 = .35) showed a lower achievable bandwidth. The root locus (Figure 47) does not show much change for the T_1 = .35 versus $T_1 = A$ configuration (Figure 42) but the Nichols plots (Figures 50 and 55) show the bandwidth has decreased from .43 rad/sec to .33 rad/sec. The T_1 = .35 case also had a much higher inner-loop lead (τ_L = 3.67 sec) than the $T_1 = A$ configuration (τ_L = .97 sec).

An analysis was also performed on the Extra-High q-augmented configuration to see what improvement the high augmentation gain would yield. The root locus (Figure 48) and Nichols plot (Figure 56) show lower altitude loop bandwidth (.38 rad/sec). However, the inner pitch attitude loop for the Extra-High q configuration had a lead time constant of only .21 sec instead of .97 sec for the High q configuration. This penalizes the altitude loop bandwidth since the pilot could most likely provide more lead. The lead provided in the High q-configuration at 1 rad/sec is $\tan^{-1}$ (.97)(1.) = 44 degs. The lead provided in the Extra-High q-augmented configuration at 1 rad/sec is $\tan^{-1}$ (.21) (1.) = 12 degrees. Therefore to add the extra 32 degs of lead, a lead term of $\frac{\tan 32^o}{1 \text{ rad/sec}}$ = .63 sec was added to the altitude control pilot model:

$$Y_{P_h} = K_{P_h} (.63s + 1)$$

The result on the root locus (Figure 49) and Nichols plot (Figure 57) is a higher bandwidth than was achieved with the High q-configuration (.5 rad/sec versus .43 rad/sec). This increases the altitude-loop bandwidth up to where it would have been for the High q-augmented configuration if the pilot had been shifted forward approximately 70 feet for an X_{MP} = 120 ft and X_{PCR} = 60 feet (see Figure 58 for ω_{BW_h} versus X_{PCR}). This improvement was confirmed from the experiment results for the Extra-High q-augmented configuration (PR = 4) compared to those for the High q-augmented configuration with X_{MP} = 110 ft (PR = 3 and 4-1/2).

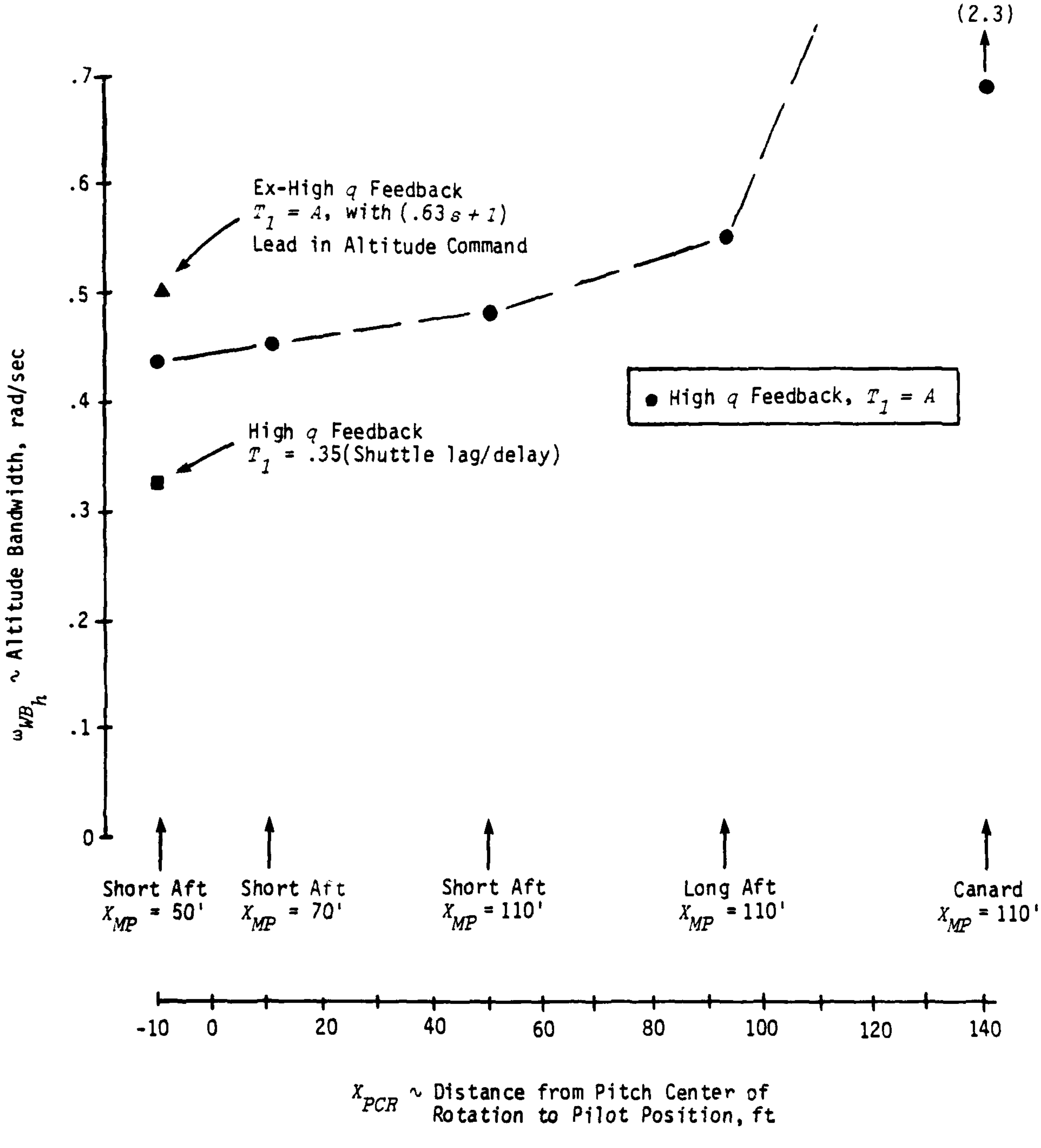


Figure 58. ALTITUDE BANDWIDTH VS PILOT POSITION - CENTER OF ROTATION (X_{PCR})

Pilot rating and pilot-induced oscillation rating are correlated with the calculated altitude loop bandwidth in Figures 59 and 60; the trend towards better ratings with high bandwidth can be seen. Though not enough samples were taken to absolutely define flying qualities boundaries, it appears that a bandwidth of greater than .5 rad/sec may be necessary for Level 1 ratings. This correlates well with data obtained by the Dutch in an NLR study (Reference 11). They used the same altitude control loop pilot model in a medium transport landing approach experiment, and proposed a .55 rad/sec altitude bandwidth as necessary for Level 1 flying qualities.

It is also interesting to note that by decreasing the effective time delay from .35 sec to .10 sec and increasing the q-augmentation level, the Short Aft Tail configuration with equivalent shuttle delay can be improved so that the altitude bandwidth increases from .33 rad/sec to .5 rad/sec. This assumes that the pilot could provide the required lead in the altitude loop. In the flight evaluations, these changes resulted in improved pilot ratings from 9 to 4 and PIO ratings from 4 to 2.

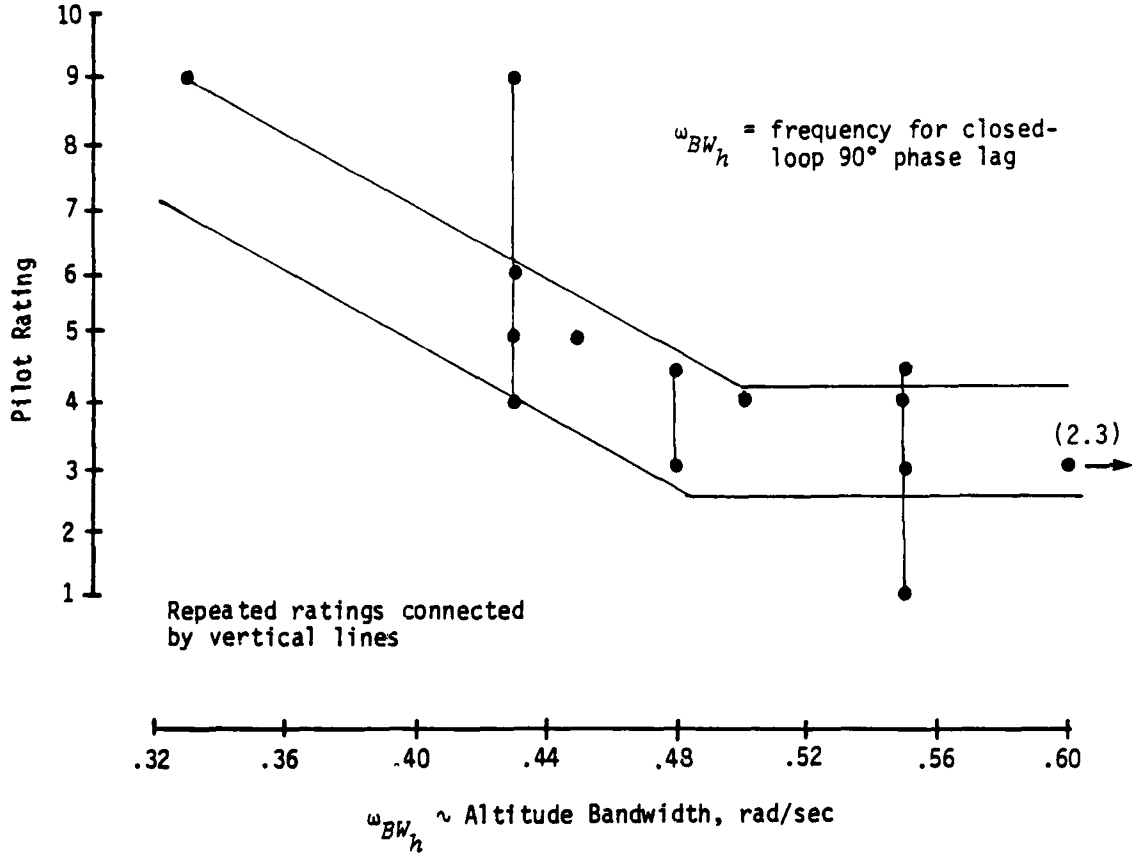


Figure 59. PILOT RATING VS ALTITUDE BANDWIDTH

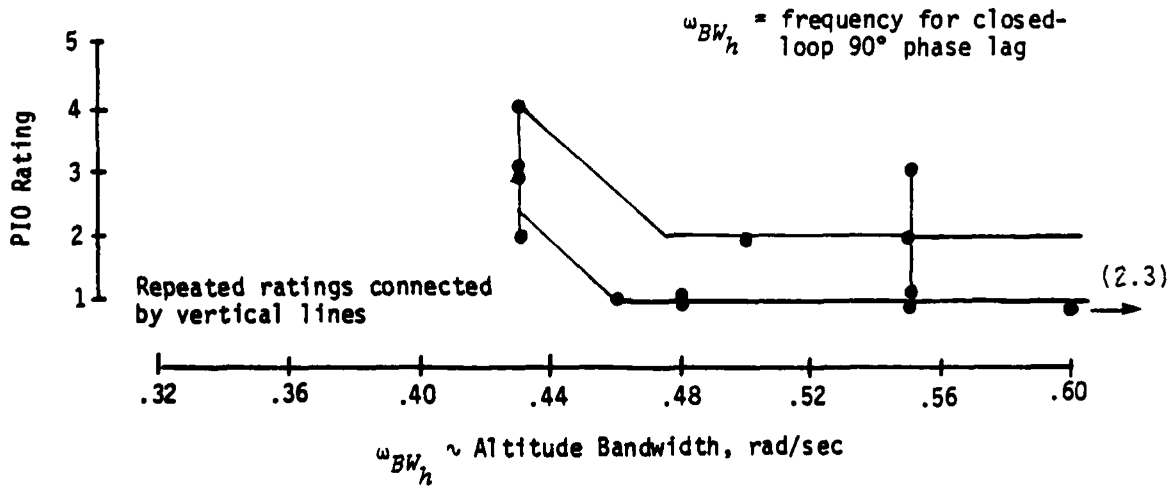


Figure 60. PIO RATING VS ALTITUDE BANDWIDTH

4.6 TURBULENCE RESPONSE

A thorough discussion of the effects of turbulence would be quite lengthy because the turbulence field has many components and the airplane has many responses that could be considered. Several gust transfer functions are listed in Appendix I. For purposes of illustration, however, only two figures are considered. Figures 61 and 62 present the θ/α_g and V_I/α_g turbulence frequency responses for the following Long Aft Tail configurations — Unaugmented, High α-feedback, and High q-feedback. These transfer functions show that in the low range of frequencies, i.e. less than 1.0 rad/sec, the High α-augmented configuration is the most responsive to turbulence, while the High q-augmented configuration is the least responsive. The unaugmented configuration is between the two in its level of turbulence response.

The large variation of the pitch attitude and inertial speed responses to angle of attack gust inputs exhibited in Figures 61 and 62 at low frequency is caused by the effect of the augmentation system on both the denominator and the numerators of the gust transfer functions. The low-frequency factors of the θ/α_g transfer function for the three configurations illustrated on Figure 61 are as follows:

$$\frac{\theta}{\alpha_{g_{High\ q}}} = \frac{.36(0)(.034)}{(.042)[.72,.74](1.43)} \; X \text{ higher frequency terms}$$

$$\frac{\theta}{\alpha_{g_{Unaug}}} = \frac{.36(0)(.036)}{(-.173)[.4,.2](1.18)} \; X \text{ higher frequency terms}$$

$$\frac{\theta}{\alpha_{g_{High\ \alpha}}} = \frac{.36(.057)(1.01)}{[.045,.132][.73,.80]} \; X \text{ higher frequency terms}$$

Although literal expressions for the gust transfer function numerators have not been developed for the various augmentation configurations, it is clear from the numerical examples listed above and in Appendix I that the effects

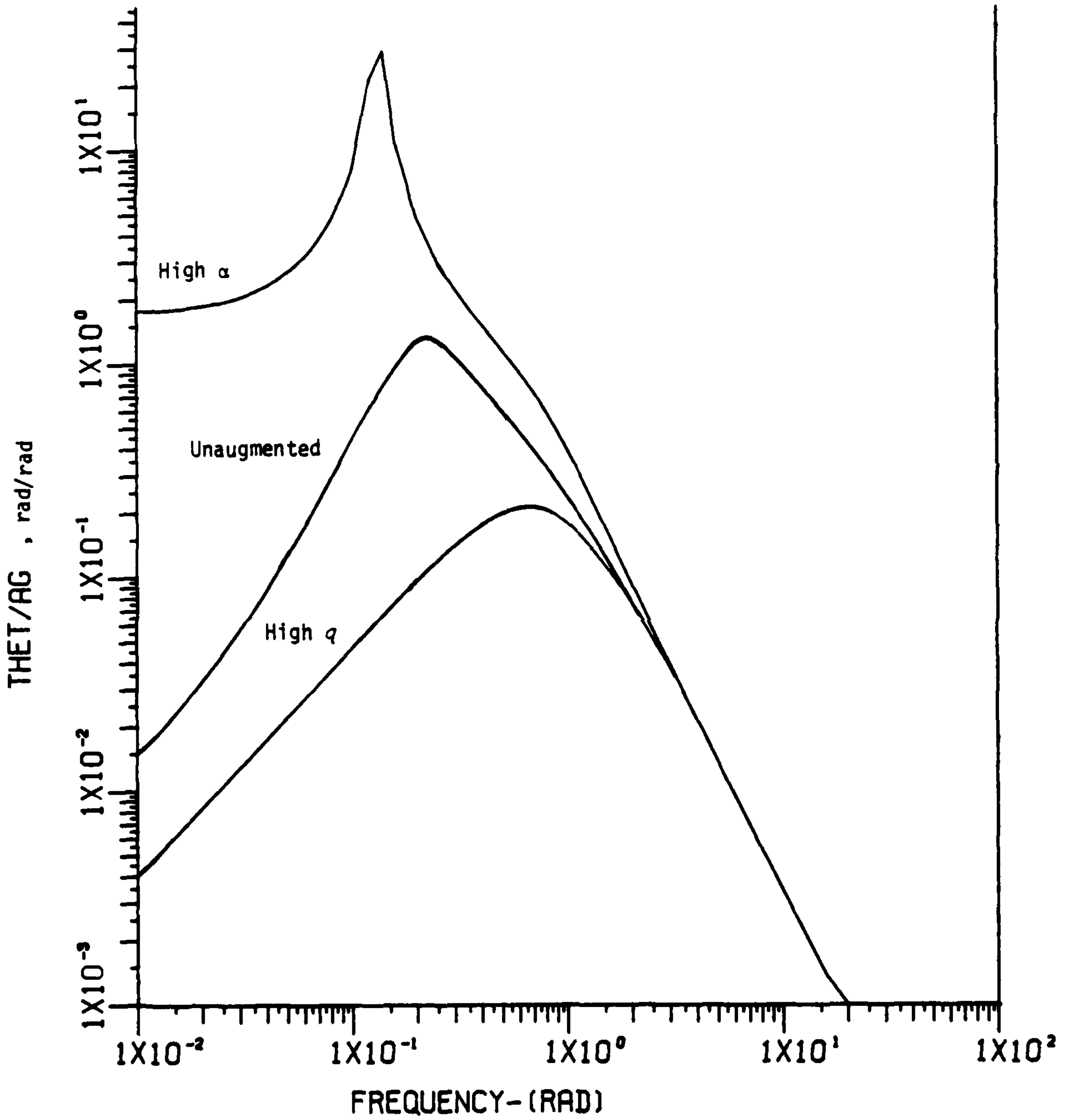


Figure 61. LONG AFT TAIL, TURBULENCE RESPONSE, θ/α_g

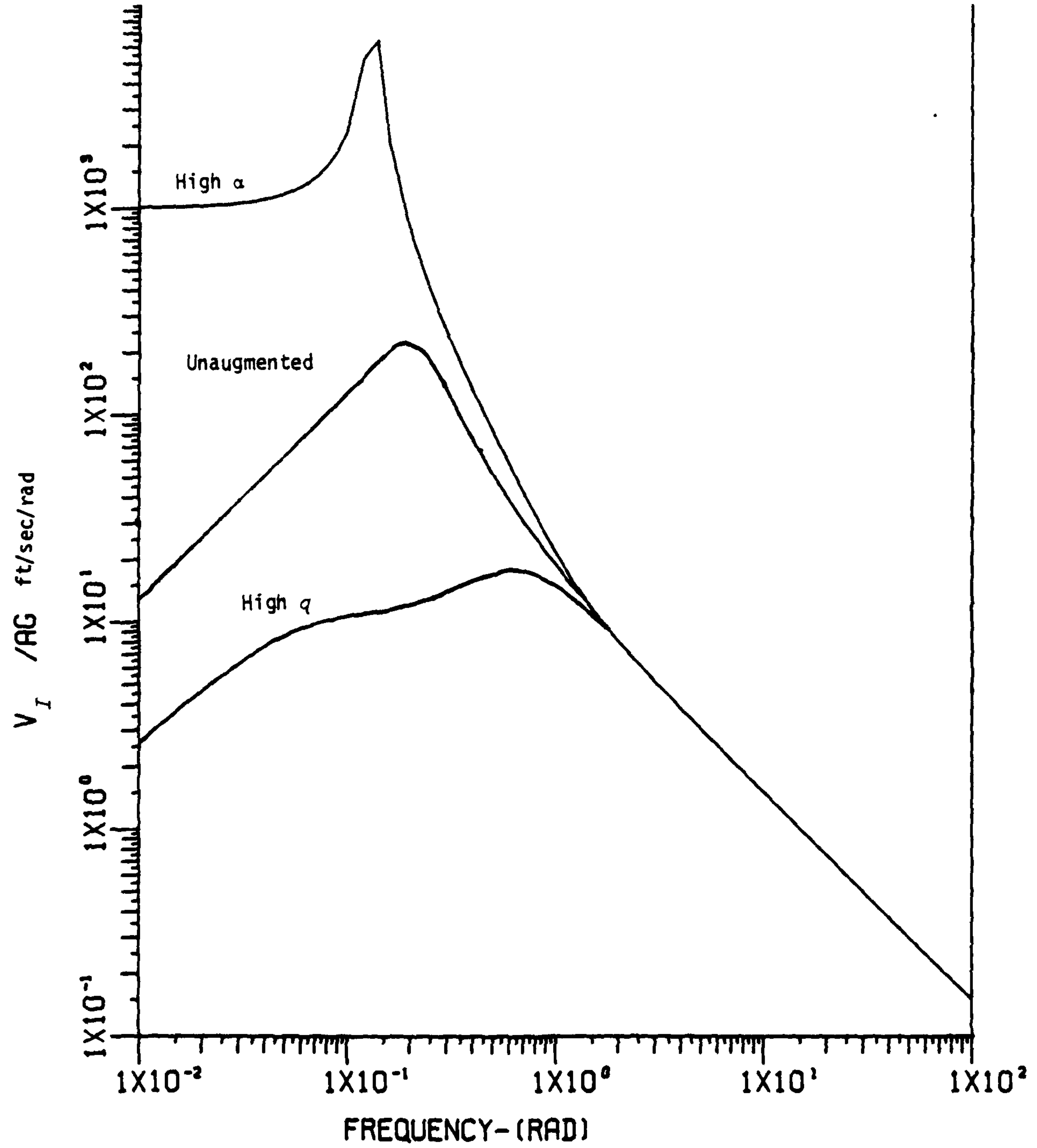


Figure 62. LONG AFT TAIL TURBULENCE RESPONSE, V_I/α_g

of the augmentation system on the transfer function numerators are significant and must be considered together with the effect on the characteristic equation. The effects occur at frequencies with high α_g power (Fig. 11).

The comments by the evaluation pilots concerning the responses of the various configurations to turbulence are generally consistent with the characteristics exhibited on Figures 61 and 62 and with other gust transfer functions not illustrated by figures. Note that the pilot comments are in terms of observation of airspeed whereas the transfer function illustrated in Figure 62 is for the inertial velocity response to angle-of-attack gusts.

All of the configurations were described as slightly ponderous in turbulence. This was due to the low short-period frequency of all of the stable configurations. For the unaugmented, unstable configurations, the airspeed control was a problem in IFR flight because the pitch attitude tended to drift if unattended; also, the slow thrust response of the engines complicated airspeed control. Heave disturbances with the lack of attitude changes in turbulence were also noted. With the higher α-augmented configurations, the pilots complained about the attitude disturbances in turbulence. They described the airplane as being very ponderous and hard to manage on the ILS, and the increased workload required in the pitch axis was objectionable. It took a long time to correct disturbances in speed and pitch attitude. With the higher q-augmented configurations, turbulence was noticed but the pilots said they did not have to do anything and it was not a problem.

Lateral-directionally, all of the configurations received comments about their wallowing nature in turbulence. This was primarily due to their low total damping, $\zeta_d \omega_d$ = .28, and time to half amplitude of approximately 2.5 seconds. This, along with the high rudder forces, made it difficult to damp out the sideslip excited in turbulence. Roll motions were also noted by the pilots in turbulence, but were generally not a problem. Only with the configurations where the pilot position was high above the stability axis (Z_{sp} = -36 ft) did the pilots comment about the poor ride qualities in turbulence. With the higher pilot position, the roll accelerations due to turbulence and pilot corrections translated into large lateral accelerations which were described as objectionable.

4.7 DIRECT LIFT CONTROL

As the *flight evaluation program* continued, it became obvious that the Short Aft Tail configurations were presenting the pilots extreme flight path control problems as they neared the ground. Many of the approaches, even with minimum levels of delay, resulted in PIO's in the flare maneuver. PIO ratings of 3 or worse were the rule with the high augmented configurations. The problem was basically due to the fact that the pilot was sitting ten feet behind the pitch center of rotation in these configurations. The pilot would use his pitch control to bend the flight path to reduce his rate of sink in the flare. The immediate effect was a sinking motion, perhaps causing him to overcontrol. When pushing forward, the opposite would happen — the aircraft would tend to heave up as it rotated nose-down. This rapidly degenerated into a PIO or the pilot had to abandon the task and settle for very long, unacceptable touchdowns.

It was speculated that if the pilots had a direct control for flight path angle that did not require the aircraft to rotate, the PIO's could be eliminated and pilot ratings improved. A *direct lift controller* that produced pure lift without pitching moment or drag was included in the model for this purpose. It was operated from a thumb wheel on the throttle handle. Full deflection of the wheel ($\pm 160^{\circ}$) produced a ΔC_L of $\pm .3$. This translated to a $\pm .2$ g capability at 150 KIAS. There was no force/feel on this controller, but a slight detent could be felt around the zero deflection point. Rotating the wheel upward resulted in positive lift. A $\frac{1}{.1s+1}$ filter was added to eliminate inadvertent high frequency commands. The direct lift controller (DLC) was evaluated with the High α and High q-augmented configurations by one of the pilots.

Results of this limited evaluation were encouraging. After a couple of approaches to learn how to use the DLC, the pilot felt he had a better control over sink rate in the flare. Pilot rating and PIO rating improvements are shown in Table XI. The pilot used the DLC only in the flare portion of the approach for sink rate control. He used the pitch controller in the upper portion of the approach and for attitude control in the flare and touchdown. He described his major difficulties as learning how to use four controllers (elevator, aileron, throttle, and DLC) at the same time, and knowing how much

TABLE XI

PILOT RATING AND PIO RATING

COMPARISONS FOR DIRECT LIFT CONTROL

Configuration: Short Aft Tail $X_{MP} = 50$ *feet* $T_1 = A$	Pilot Rating		PIO Rating	
	No DLC	With DLC	No DLC	With DLC
High α Feedback	9,8	6	5,4	3
High q Feedback	9,5	5	4,3	2

lift control he had in at a particular moment. He felt more experience with the controller and a force/feel system or at least a centering spring may have improved his opinion of the DLC.

Section 5
CONCLUSIONS

1. The pilot rating and comment data obtained in this experiment for a million-pound airplane exhibit significant effects of the following experiment variables:

    - Augmentation type and level of loop gain, i.e., angle of attack feedback or pitch rate feedback with proportional plus integral in forward path and automatic elevator for turns.
    - Pilot location relative to the center of rotation for elevator commands.
    - Lag and time delay in the command path for both pitch and roll.
    - Slow thrust response coupled with backside aerodynamic characteristics.
    - Direct lift control.
    - Lateral acceleration at the pilot location.

    Neither the MIL-F-8785C requirements nor any of several proposed requirements for pitch and control system dynamics were capable of correlating the experiment results without significant modification or extension.

2. The pitch rate augmentation system was generally preferred over the angle of attack augmentation. This was especially true for the Short Aft Tail configurations with the pilot behind the center of rotation. This was due to the lower turbulence response, attitude-hold feature, and level turn capability without pitch inputs with the q-augmented configurations.

3. The pilot ratings were degraded for the cases where the pilot was located near or behind the center of rotation.

4. The evaluation pilots tended to apply a less demanding standard of maneuverability than for previous landing approach studies because the configurations were defined to be very large, one-million pound, Class III aircraft. The closed-loop pitch attitude bandwidth requirement for the landing approach task with this Class of aircraft appears to be 1.5 rad/sec.

5. The degradation caused by time delay was less severe than in previous landing approach studies in both pitch and roll. This is primarily a result of the decreased bandwidth demanded by the pilots for this class airplane. The present equivalent time delay requirements of MIL-F-8785C appear to be conservative for this class of airplane and flight phase. Data is presented which suggests that the amount of time delay that can be tolerated in the command path is inversely related to the dynamic bandwidth required to perform the task.

6. When the pilot position is forward of the center of rotation, the pitch acceleration response to control provides an earlier linear acceleration cue at the pilot position that is easily perceived by the pilot and serves to confirm to the pilot that the airplane is responding to his command. When the pilot is located far ahead of the center of rotation, the linear acceleration cue is amplified immediately following the transmission delay through the control system but before the lag associated with the short-period mode. This effect may contribute to the higher tolerance to control system time delay observed in this experiment.

7. A multi-loop analysis which modeled an outer altitude control loop in series around the inner pitch attitude loop provided insight into the effects of pilot location relative to the center of rotation. A low-frequency closed-loop pole goes unstable at relatively low gain and frequency with the pilot aft of the center of rotation. As the pilot moves further forward of the center of rotation, this complex mode

remains stable and closed-loop bandwidth of the altitude control loop increases. A closed-loop altitude bandwidth of .5 rad/sec appears necessary for Level 1 ratings. For the Short Aft Tail configurations, it was shown that increasing the level of q-augmentation had a similar effect on altitude bandwidth as moving the pilot forward.

8. Evaluation of the shuttle-like Short Aft Tail configuration with the pilot located ten feet behind the center of rotation indicated acceptable flying qualities could be achieved when the command path time delay was low and the Extra-High pitch rate augmentation was used. This aircraft design was unacceptable when time lag and delay equal to that of the shuttle was introduced into the pitch command path and the High pitch rate augmentation was used.

9. The effect of turbulence on the unaugmented configurations was relatively low except for long-term speed control due to its negative static stability. As the α-augmentation level was increased, a pitching and airspeed response to turbulence became greater at frequencies below 1 rad/sec. At the highest levels of augmentation, the response to turbulence at low frequency seriously hindered control. The effect of the pilot being very far from the center of rotation also added to the motion felt by the pilot in turbulence. As the q-augmentation level was increased, these turbulence effects became less. This was due to the low static stability of the base airplane and the long-term attitude hold of the q-feedback configurations.

10. The slow thrust response (three second time constant) to throttle caused difficulty in thrust management and forced open-loop manipulation of the throttles, i.e., set and wait to see if further adjustment is required. This complicated airspeed control and degraded the pilot ratings, especially for the α-augmented configurations. The slow thrust response compounded airspeed control for these configurations since they were also slightly on the "backside" at the trim speed.

11. Reduction in n_z/α from 4.2 to 2.0 g/rad caused pilot ratings to degrade by PR = 2-3 points. The degradation, however, was more related to the pitch control force and thrust required in turns than to pitch dynamics.

12. Direct lift control, commanded by a thumb wheel, mounted on the throttle lever, improved control of sink rate during flare and touchdown for the Short Aft Tail configuration. More pilot experience and a force/feel system with the direct lift control would be necessary for a thorough evaluation.

13. The lateral-directional augmentation system provided excellent turn coordination and minimal excitation of sideslip in turning maneuvers.

14. The low frequency Dutch roll mode excited by turbulence, lineup, and crosswind corrections required a special trimming technique and the response to rudder pedal inputs was slow. Rudder forces to maneuver were heavy.

15. The combination of high roll damping and pilot location high above the X-stability axis caused degradation in pilot ratings due to lateral acceleration in rolling and turning maneuvers. The data tend to verify the lateral acceleration parameter: $\left.\dfrac{n_{y_{pilot_{max}}}}{p_{max}}\right|_{\substack{step\ input \\ t\ <\ 2.5\ sec}}$ from Reference 3.

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Appendix I
TRANSFER FUNCTIONS

The following is a tabulation of important transfer functions of the evaluated configurations. It is written in the shorthand notation where:

$K(a)[\zeta,\omega]$ is equivalent to $K(s+a)[s^2 + 2\zeta\omega s + \omega^2]$

The following factors are present in each of the longitudinal denominators:

Approximately (20)	=	elevator servo (slightly lower for q-feedback)
(.333)	=	throttle servo
[.7,25]	=	pitch control feel system } As noted
[.7,15]	=	" " " " } As noted

The lateral-directional denominators contain the following factors:

(20)	=	aileron or rudder servo
[.7,25]	=	roll control feel system
[.7,15]	=	yaw control feel system

The following gradients and gearings are present in the numerator gains:

	Gradient	Gearing
Pitch	.1 inch/pound	2.5 deg/inch (α-feedback)
		1.25 deg/inch (q-feedback)
		(pitch gearing was negative for Canard configuration)
Roll	2. deg/pound	1.5 deg/deg (τ_R = .87)
		3.0 deg/deg (τ_R = .44)
Yaw	.01 inch/pound	-15. deg/inch

In addition to the transfer function factors shown, the following delay/lag factors should be added to represent the level of delay flown in each axis:

	Delay Level	Additional Transfer Function Factors	and Description
Pitch	A	$e^{-.06s}$	TIFS pitch model-following delay = .06 sec
	B	$\frac{9.e^{-.06s}}{(9)}$	"A" plus command filter $\frac{1}{.111s+1}$
	C	$\frac{9.e^{-.13s}}{(9)}$	"B" plus extra command delay = .07 sec
	C'	$\frac{9.e^{-.24s}}{(9)}$	"B" plus extra command delay = .18 sec (Equivalent to shuttle lags)
Roll	A	$e^{-.12s}$	TIFS roll model-following delay = .12 sec
	B	$\frac{4.8e^{-.12s}}{(4.8)}$	"A" plus command filter $\frac{1}{.21s+1}$
	C	$\frac{4.8e^{-.20s}}{(4.8)}$	"B" plus extra command delay = .08 sec

All angular units in radians, velocity in ft/sec; n_z positive down.

LONGITUDINAL TRANSFER FUNCTIONS

CONFIGURATION: Long Aft Tail α-Feedback $K_\alpha = 0.$ (Unaugmented)

Denominator [.406,.215](1.18)(-.173)(20)(.333)[.7,25.]

$N^{\theta}_{F_{ES}}$ 25.6 (.526)(.059)(.333)

$N^{\alpha}_{F_{ES}}$ 1.77 [.0735, .177](15.1)(.333)

$N^{V_I}_{F_{ES}}$ 26.6 (1.02)(-16.9)(.333)

$N^{n_{zp}(110')}_{F_{ES}}$ -73.6 [.231, 1.25](-.003)(0)(.333)

$N^{n_{z_{CG}}}_{F_{ES}}$ 14.0 (3.18)(-.003)(-2.53)(0)(.333)

$N^{V_I}_{\delta_T}$ 2.13 (1.18)(-.026)(0)(20)[.7,25.]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 (.931)(-.312)(20)[.7,25.]

$N_{u_g}^{\theta}$ .00013 (-2.25)(0)(20)(.333)[.7,25.]

$N_{u_g}^{\dot{V}_I}$ -.028 [.99,1.02](-.324)(20)(.333)[.7,25.]

$N_{u_g}^{V}$ 1. (-.026)(1.18)(0)(0)(20)(.333)[.7,25.]

$N_{\alpha_g}^{\theta}$ .36 (.036)(0)(20)(.333)[.7,25.]

$N_{\alpha_g}^{V_I}$ 15. (1.24)(-.62)(0)(20)(.333)[.7,25.]

<u>CONFIGURATION</u>: Long Aft Tail α-Feedback K_α=-.61 (Low)

Denominator (.831)(.268)(.088)(-.0028)(20)(.333)[.7,25.]

F_{ES} Numerators - Same as those for Unaugmented.

$N_{\delta_T}^{V_I}$ 2.13 (.834)(.322)(0)(20)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 (.607)(-.0028)(20)[.7,25.]

<u>CONFIGURATION</u>: Long Aft Tail α-Feedback K_α=-.90 (Medium)

Denominator [.897,.647][.120,.102](20)(.333)[.7,25.]

F_{ES} Numerators - same as those for Unaugmented.

$N_{\delta_T}^{V_I}$ 2.13 [.90,.641](0)(20)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 [.81,.368](20)[.7,25.]

CONFIGURATION: Long Aft Tail α-Feedback K_α=-1.35 (High)

Denominator [.732,.805][.045,.132](20)(.333)[.7,25.]

F_{ES} Numerators - same as those for Unaugmented.

$N^{V_I}_{\delta_T}$ 2.13 [.731,.794](0)(20)[.7,25.]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 [.497,.590](20)[.7,25.]

$N^{\theta}_{u_g}$ .00013 (.389)(0)(13.9)(.333)[.7,25.]

$N^{V_I}_{u_g}$ -.028 [.483,.598](1.12)(20)(.333)[.7,25.]

$N^{V}_{u_g}$ 1 [.731,.794](0)(0)(20)(.333)[.7,25.]

$N^{\theta}_{\alpha_g}$ .36 (1.01)(.057)(19.0)(.333)[.7,25.]

$N^{V_I}_{\alpha_g}$ 15. [.70,.995](-.762)(20)(.333)[.7,25.]

CONFIGURATION: Long Aft Tail α-Feedback K_α=-2.10 (Extra-High)

Denominator [.589,1.006][.037,.15](20)(.333)[.7,25]

F_{ES} Numerators - same as those for Unaugmented.

$N^{V_I}_{\delta_T}$ 2.13 [.584,1.00](0)(20)[.7,25]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 [.339,.838](20)[.7,25]

CONFIGURATION: Long Aft Tail α-Feedback $K_\alpha=-1.45$ (High), $n_z/\alpha=3.$

Denominator [.656,.791][.049,.143](20)(.333)[.7,25.]

$N^{\theta}_{F_{ES}}$ 25.6 (.353)(.089)(.333)

$N^{\alpha}_{F_{ES}}$ 1.77 [.0735,.177](15.1)(.333)

$N^{V_I}_{F_{ES}}$ 34.9 (1.025)(-9.56)(.333)

$N^{n_{zp}(110')}_{F_{ES}}$ -73.6 [.188,1.08](-.0023)(0)(.333)

$N^{n_{z_{CG}}}_{F_{ES}}$ 14.0 (2.79)(-.0028)(-2.14)(0)(.333)

$N^{V_I}_{\delta_T}$ 2.13 [.654,.782](0)(20)[.7,25.]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 [.464,.629](20)[.7,25.]

CONFIGURATION: Long Aft Tail α-Feedback $K_\alpha=-1.60$ (High) $n_z/\alpha=2$

Denominator [.564,.790][.055,.156](20)(.333)[.7,25]

$N^{\theta}_{F_{ES}}$ 25.6 [.829,.179](.333)

$N^{\alpha}_{F_{ES}}$ 1.77 [.0735,.177](15.1)(.333)

$N^{V_I}_{F_{ES}}$ 43.1 (1.02)(-5.06)(.333)

$N^{n_{zp}(110')}_{F_{ES}}$ -73.6 [.132,.879](-.0013)(0)(.333)

$N^{n_{z_{CG}}}_{F_{ES}}$ 14.0 (2.32)(-.0014)(-1.67)(0)(.333)

$N^{V_I}_{\delta_T}$ 2.13 [.561,.784](0)(20)[.7,25]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 [.425,.683](20)[.7,25]

<u>CONFIGURATION:</u> Long Aft Tail Q-Feedback T_q=1., K_q=-.6 (Low)

Denominator [.326,.395](1.205)(-.0038)(0)(19.7)(.333)[.7,25.]

$N^{\theta}_{F_{ES}}$ 7.69 (1.)(.526)(.0587)(.333)

$N^{\alpha}_{F_{ES}}$ .534 [.0735,.177](15.1)(1.)(.333)

$N^{V_I}_{F_{ES}}$ 7.98 (1.)(1.02)(-16.9)(.333)

$N^{n_{zp}(110')}_{F_{ES}}$ -22.1 [.231,1.25](1.)(-.003)(0)(.333)

$N^{n_{z_{CG}}}_{F_{ES}}$ 4.18 (3.18)(1.)(-.0031)(-2.53)(0)(.333)

$N^{V_I}_{\delta_T}$ 2.13 [.313,.364](1.20)(0)(19.7)[.7,25.]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 (.909)(-.0072)(0)(19.7)[.7,25.]

<u>CONFIGURATION:</u> Long Aft Tail q-Feedback T_q=1., K_q=-1.3 (Medium)

Denominator [.477,.547](1.25)(.0261)(0)(19.4)(.333)[.7,25.]

$N^{\theta}_{F_{ES}}$ 16.7 (1.)(.526)(.0587)(.333)

$N^{\alpha}_{F_{ES}}$ 1.15 [.0735,.177](15.1)(1.)(.333)

$N^{V_I}_{F_{ES}}$ 17.3 (1.)(1.02)(-16.9)(.333)

$N^{n_{zp}(110')}_{F_{ES}}$ -47.9 [.231,1.25](1.)(-.003)(0)(.333)

$N^{n_{z_{CG}}}_{F_{ES}}$ 9.05 (3.18)(1.)(-.0031)(-2.53)(0)(.333)

$N^{V_I}_{\delta_T}$ 2.13 [.492,.53](1.25)(0)(19.4)[.7,25.]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 (.846)(.397)(0)(19.4)[.7,25.]

<u>CONFIGURATION:</u> Long Aft Tail q-Feedback $T_q=1.$, $K_q=-2.75$ (High)

Denominator [.723,.737](1.43)(.0422)(0)(18.6)(.333)[.7,25.]

$N^{\theta}_{F_{ES}}$ 35.2 (1.)(.526)(.0587)(.333)

$N^{\alpha}_{F_{ES}}$ 2.43 [.0735,.177](15.1)(1.)(.333)

$N^{V_I}_{F_{ES}}$ 36.6 (1.)(1.02)(-16.9)(.333)

$N^{n_{zp}(110')}_{F_{ES}}$ -101.3 [.231,1.25](1.)(-.003)(0)(.333)

$N^{n_z(50')}_{F_{ES}}$ -35.4 [.132,2.10](1.)(-.0031)(0)(.333)

$N^{n_{z_{CG}}}_{F_{ES}}$ 19.2 (3.18)(1.)(-.0031)(-2.53)(0)(.333)

$N_{\delta_T}^{V_I}$ 2.13 [.735,.736](1.42)(0)(18.6)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 [.954,1.043](0)(18.6)[.7,25.]

$N_{u_g}^{\theta}$ .00013 (-2.25)(0)(0)(20)(.333)[.7,25.]

$N_{u_g}^{V_I}$ -.028 [.936,1.18](.837)(0)(18.6)(.333)[.7,25.]

$N_{u_g}^{V}$ 1. [.735,.736](1.42)(0)(0)(18.6)(.333)[.7,25.]

$N_{\alpha_g}^{\theta}$ .36 (.0335)(0)(0)(20)(.333)[.7,25.]

$N_{\alpha_g}^{V_I}$ 15. (1.64)(.343)(0)(0)(18.6)(.333)[.7,25.]

<u>CONFIGURATION:</u> Canard α-Feedback $K_\alpha = 0.$ (Unaugmented)

Denominator [.444,.218](1.22)(-.163)(20)(.333)[.7,25.]

$N_{F_{ES}}^{\theta}$ 26.3 (.527)(.058)(.333)

$N_{F_{ES}}^{\alpha}$ 3.12 [.0876,.185](-7.81)(.333)

$N_{F_{ES}}^{V_I}$ 46.8 (9.12)(1.10)(.333)

$N_{F_{ES}}^{n_{zp}(110')}$ -114.5 [.295,1.02](-.0023)(0)(.333)

$N_{F_{ES}}^{n_{z_{CG}}}$ -24.5 [.150,2.17](-.0023)(0)(.333)

$N_{\delta_T}^{V_I}$ 2.13 (1.22)(.0028)(0)(20)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 (.931)(-.312)(20)[.7,25.]

CONFIGURATION: Canard α-Feedback $K_\alpha = -.62$ (Low)

Denominator (.828)(.291)(.071)(.0057)(20)(.333)[.7,25.]

F_{ES} Numerators - same as those for Unagumented.

$N_{\delta_T}^{V_I}$ 2.13 (.832)(.335)(0)(20)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 (.599)(.0050)(20)[.7,25.]

CONFIGURATION: Canard α-Feedback $K_\alpha = -.88$ (Medium)

Denominator [.906,.634][.128,.101](20)(.333)[.7,25.]

F_{ES} Numerators - same as those for Unaugmented.

$N_{\delta_T}^{V_I}$ 2.13 [.912,.628](0)(20)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 [.842,.355](20)[.7,25.]

CONFIGURATION: Canard α-Feedback $K_\alpha = -1.36$ (High)

Denominator [.712,.788][.0416,.135](20)(.333)[.7,25.]

F_{ES} Numerators - same as those for Unaugmented.

$N_{\delta_T}^{V_I}$ 2.13 [.710,.779](0)(20)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 [.493,.594](20)[.7,25.]

CONFIGURATION: Canard α-Feedback K_α=-2.3 (Extra-High)

Denominator [.515,1.013][.038,.158](20)(.333)[.7,25.]

F_{ES} Numerators - same as those for Unaugmented.

$N_{\delta_T}^{V_I}$ 2.13 [.509,1.01](0)(20)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 [.315,.893](20)[.7,25.]

CONFIGURATION: Canard q-Feedback T_q=1, K_q=-2.81 (High)

Denominator [.748,.723](1.55)(.0422)(0)(18.6)(.333)[.7,25.]

$N_{F_{ES}}^{\theta}$ 36.9 (1)(.527)(.058)(.333)

$N_{F_{ES}}^{\alpha}$ 4.37 [.0876,.185](1)(-7.81)(.333

$N_{F_{ES}}^{V_I}$ 65.8 (1)(1.10)(9.12)(.333)

$N_{F_{ES}}^{n_{zp}(110')}$ -160.6 [.295,1.02](-.0023)(1)(0)(.333)

$N_{F_{ES}}^{n_z(50')}$ -91.[illegible] [.228,1.34](-.0023)(1)(0)(.333)

$N_{F_{ES}}^{n_{z_{CG}}}$ -34.5 [.150,2.17](-.0023)(1)(0)(.333)

$N_{\delta_T}^{V_I}$ 2.13 [.760,.723](1.55)(0)(18.6)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 [.956,1.06](0)(18.6)[.7,25.]

CONFIGURATION: Short Aft Tail α-Feedback, $K_\alpha = -.85$ (Medium)

Denominator [.927,.630][.148,.0956](20)(.333)[.7,25.]

$N^{\theta}_{F_{ES}}$ 25.1 (.527)(.059)(.333)

$N^{\alpha}_{F_{ES}}$ 5.94 [.065,.170](4.84)(.333)

$N^{V_I}_{F_{ES}}$ 89.4 (.975)(-5.16)(.333)

$N^{n_{zp}(50')}_{F_{ES}}$ 7.92 (4.24)(-.0037)(-3.29)(0)(.333)

$N^{n_{zCG}}_{F_{ES}}$ 46.8 (1.89)(-.0037)(-1.24)(0)(.333)

$N^{V_I}_{\delta_T}$ 2.13 [.934,.625](0)(20)[.7,25.]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 [.895,.334](20)[.7,25.]

CONFIGURATION: Short Aft Tail α-Feedback, $K_\alpha = -1.25$ (High)

Denominator [.773,.788][.0539,.126](20)(.333)[.7,25.]

F_{ES} Numerators - same as those for Medium gain

$N^{V_I}_{\delta_T}$ 2.13 [.774,.777](0)(19.9)[.7,25.]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 [.536,.549](20)[.7,25.]

CONFIGURATION: Short Aft Tail q-Feedback, $T_q=1$, $K_q=-1.05$ (Medium)

Denominator [.395,.503](1.19)(.0194)(0)(19.5)(.333)[.7,25.]

$N^{\theta}_{F_{ES}}$ 13.2 (.527)(.059)(1)(.333)

$N^{\alpha}_{F_{ES}}$ 3.12 [.0647,.170](4.84)(1)(.333)

$N^{V_I}_{F_{ES}}$ 46.9 (.975)(-5.16)(1)(.333)

$N^{n_{zp}(50')}_{F_{ES}}$ 4.16 (4.24)(-.0037)(-3.29)(0)(1)(.333)

$N^{n_{z_{CG}}}_{F_{ES}}$ 24.5 (1.89)(-.0037)(-1.24)(0)(1)(.333)

$N^{V_I}_{\delta_T}$ 2.13 [.405,.483](1.19)(0)(19.5)[.7,25.]

$N^{\dot{h}_{CG}}_{\delta_T}$ .542 (.878)(.241)(0)(19.5)[.7,25.]

CONFIGURATION: Short Aft Tail q-Feedback, $T_q=1$, $K_q=-2.5$ (High)

Denominator [.666,.727](1.305)(.0408)(0)(18.8)(.333)[.7,25.]

$N^{\theta}_{F_{ES}}$ 31.3 (.527)(.0593)(1)(.333)

$N^{\alpha}_{F_{ES}}$ 7.43 [.0647,.170](4.84)(1)(.333)

$N^{V_I}_{F_{ES}}$ 111.8 (.975)(-5.16)(1)(.333)

$N^{n_{zp}(50')}_{F_{ES}}$ 9.89 (4.24)(-3.29)(-.0037)(0)(1)(.333)

$N_{F_{ES}}^{n_z(70')}$ -9.85 [.030,3.75](-.0037)(0)(1)(.333)

$N_{F_{ES}}^{n_z(110')}$ -48.8 [.152,1.70](-.0036)(0)(1)(.333)

$N_{F_{ES}}^{n_{z_{CG}}}$ 58.5(1.89)(-1.24)(-.0037)(0)(1)(.333)

$N_{\delta_T}^{V_I}$ 2.13 [.680,.724](1.30)(0)(18.8)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 [.951,.976](0)(18.8)[.7,25.]

<u>CONFIGURATION:</u> Short Aft Tail q-Feedback, T_q=.5, K_q=-5.2 (Extra High)

Denominator [.671,2.212](.597)(.0547)(0)(17.5)(.333)[.7,25.]

$N_{F_{ES}}^{\theta}$ 65.2 (.527)(.0593)(2)(.333)

$N_{F_{ES}}^{\alpha}$ 15.5 [.0647,.170](4.84)(2)(.333)

$N_{F_{ES}}^{V_I}$ 232.3 (.975)(-5.16)(2)(.333)

$N_{F_{ES}}^{n_{zP}(50')}$ 20.6 (4.24)(-.0037)(-3.29)(0)(2)(.333)

$N_{F_{ES}}^{n_{z_{CG}}}$ 121.6 (1.89)(-.0037)(-1.24)(0)(2)(.333)

$N_{\delta_T}^{V_I}$ 2.13 [.671,2.213](.622)(0)(17.5)[.7,25.]

$N_{\delta_T}^{\dot{h}_{CG}}$ .542 [.698,2.31](0)(17.4)[.7,25.]

LATERAL-DIRECTIONAL TRANSFER FUNCTIONS

Z_{sp} = -18' except as noted

CONFIGURATION: $\tau_R = .87$

Denominator [.574,.486](1.15)(.0034)(20)[.7,25.](20)[.7,15.]

$N^{\phi}_{F_{AS}}$ 170.2 [.570,.483](19.8)[.7,15.]

$N^{r}_{F_{AS}}$ 8.25 [.589,.477](3.45)(14.9)[.7,15.]

$N^{\beta}_{F_{AS}}$ -.097 (.331)(-.226)(-27.9)(12.2)[.7,15.]

$N^{n_y(50')}_{F_{AS}}$ (Low, $Z_{sp}=-18'$) 88.7 [.590,.479](.256)(-.211)(19.5)[.7,15.]

$N^{n_y(70')}_{F_{AS}}$ (Low, $Z_{sp}=-18'$) 86.4 [.592,.478](.364)(-.155)(19.2)[.7,15.]

$N^{n_y(110')}_{F_{AS}}$ (Low, $Z_{sp}=-18'$) 79.6[.591,.475](.684)(-.093)(18.7)[.7,15.]

$N^{n_y(110')}_{F_{AS}}$ (High, $Z_{sp}=-36'$) 175.3 [.586,.484](.333)(-.082)(19.3)[.7,15.]

$N^{\phi}_{F_{RP}}$ -.636 (1.47)(-1.14)(18.6)[.7,25.]

$N^{r}_{F_{RP}}$ 1.80 [.0507,.244](1.17)(19.7)[.7,25.]

$N^{\beta}_{F_{RP}}$ -.196 (9.61)(1.16)(.0048)(19.7)[.7,25.]

$N^{n_y(50')}_{F_{RP}}$ (Low, $Z_{sp}=-18'$) .958 [.059,1.00](1.05)(-.024)(20)[.7,25.]

$N^{n_y(70')}_{F_{RP}}$ (Low, $Z_{sp}=-18'$) 2.12 [.056,.685](1.11)(-.022)(19.8)[.7,25.]

$N_{F_{RP}}^{n_y(110')(Low,\ Z_{sp}=-18')}$ 4.42 [.044,.500](1.14)(-.019)(19.7)[.7,25.]

$N_{F_{RP}}^{n_y(110')(High,\ Z_{sp}=-36')}$ 4.06 [.152,.534](1.09)(-.019)(19.8)[.7,25.]

<u>CONFIGURATION</u>: $\tau_R = .44$

Denominator [.573,.484](2.27)(.0018)(20)[.7,25.](20)[.7,15.]

$N_{F_{AS}}^{\phi}$ 340.3[.570,1483](19.8)[.7,15.]

$N_{F_{AS}}^{r}$ 16.5[.589,.477](3.45)(14.9)[.7,15.]

$N_{F_{AS}}^{\beta}$ -.196 (.330)(-.226)(-27.9)(12.2)[.7,15.]

$N_{F_{AS}}^{n_y(110')(Low,\ Z_{sp}=-18')}$ 160.3[.591,.475](.684)(-.093)(18.7)[.7,15.]

$N_{F_{AS}}^{n_y(110')(High,\ Z_{sp}=-36')}$ 350.1[.586,484](.333)(-.082)(19.3)[.7,15.]

$N_{F_{RP}}^{\phi}$ .130[.272,2.67](25.5)[.7,25.]

$N_{F_{RP}}^{r}$ 1.83[.170,.194](2.28)(18.5)[.7,25.]

$N_{F_{RP}}^{\beta}$ -.196 (9.59)(2.28)(.0028)(18.5)[.7,25.]

$N_{F_{RP}}^{n_y(110')(Low,\ Z_{sp}=-18')}$ 4.75[.052,.459](2.22)(-.014)(18.6)[.7,25.]

$N_{F_{RP}}^{n_y(110')(High,\ Z_{sp}=-36')}$ 4.83[.121,.464](2.14)(-.014)(18.7)[.7,25.]

Appendix II
TIME HISTORIES

This appendix presents time histories for each of the evaluated configurations for step inputs into the pitch, roll, and yaw command channels. Feel system dynamics, model-following delay, and extra time delay and lags were not included. Magnitude of inputs and command gains used were (except where noted):

pitch — 1. inch through 1. deg/inch gain: DEC STEP

roll — 1. deg through 1. deg/deg gain: DAW or DAC STEP

yaw — 1. inch through 1. deg/inch gain: DRP STEP

Notation used in the body axes system is:

Longitudinal —

Q — (q) — pitch rate, rad/sec
V — (ΔV) — incremental true airspeed, ft/sec
ALFA — ($\Delta\alpha$) — incremental angle of attack, rad
*Q** — ($\dot{q}$) — pitch acceleration, rad/sec^2
NZCG — ($n_{z_{CG}}$) — normal acceleration at center of gravity, g's
NZP — (n_{z_p}) — normal acceleration at nominal pilot station, g's
X_{MP} = 110 ft for Long Aft Tail and Canard
X_{MP} = 50 ft for Short Aft Tail
NZ50, NZ70, N110 — normal acceleration at shifted pilot position
X_{MP} = 50, 70, 110 ft for the configuration shown, g's

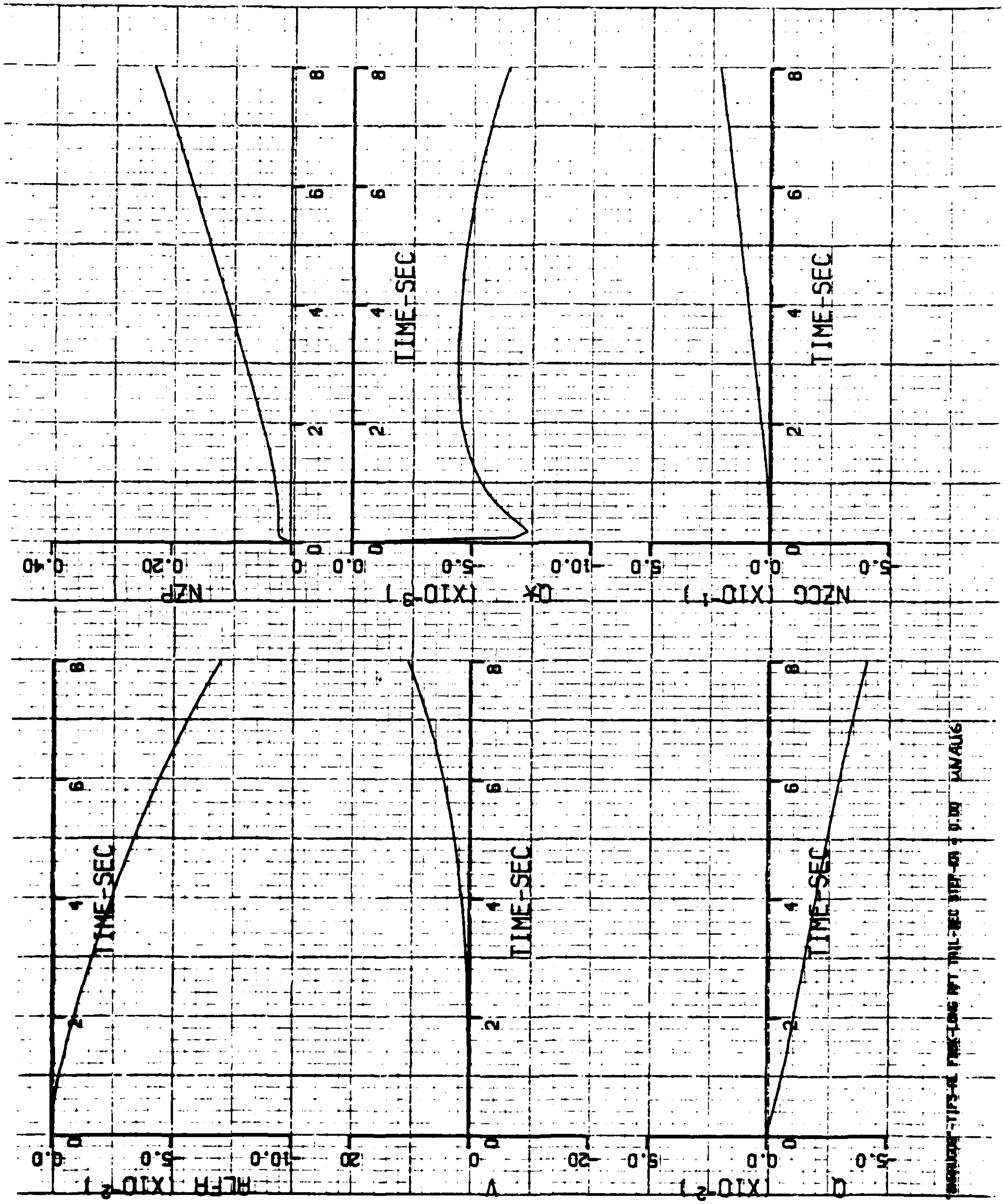
(Normal acceleration is defined to be positive down)

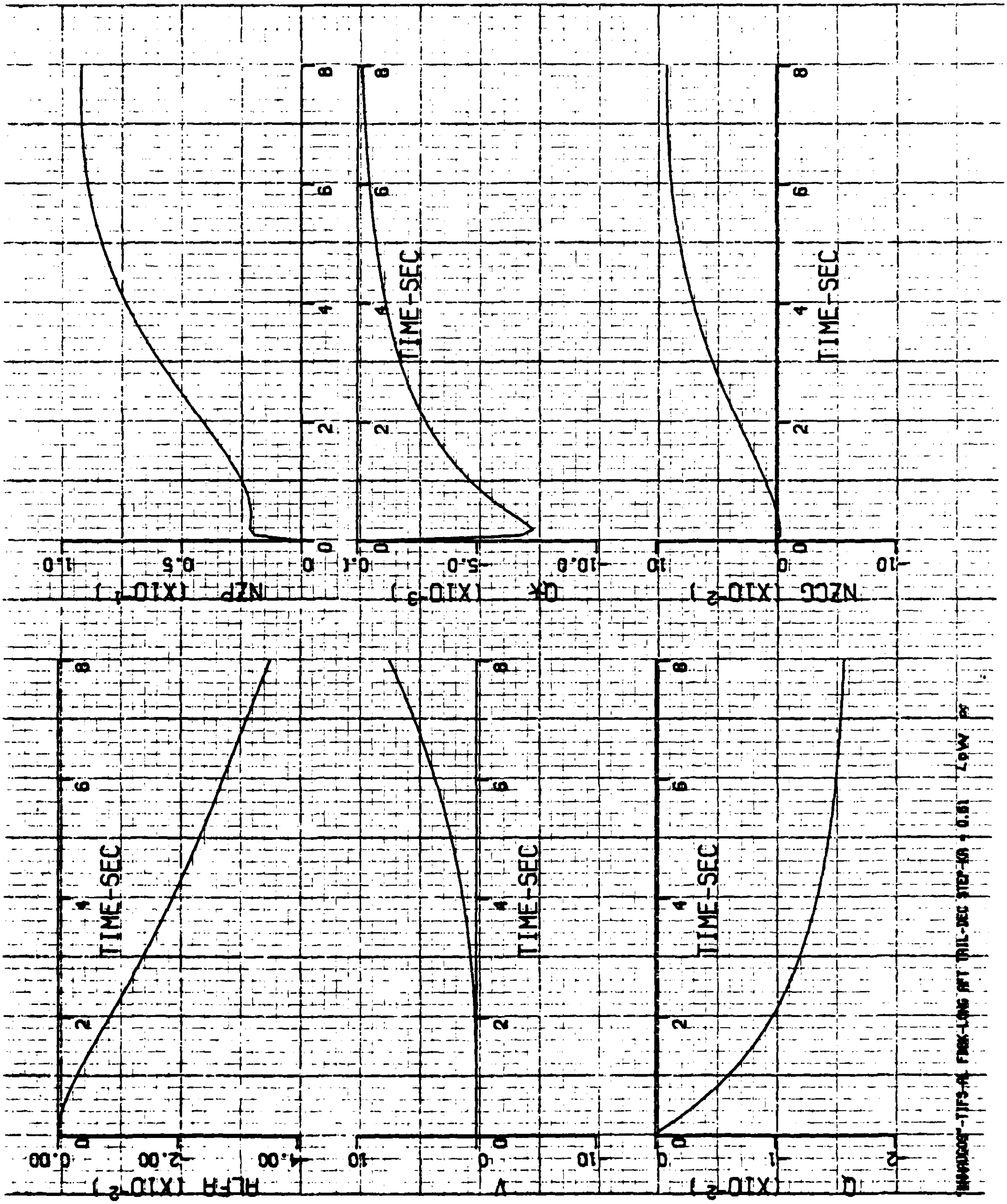
Lateral-Directional —

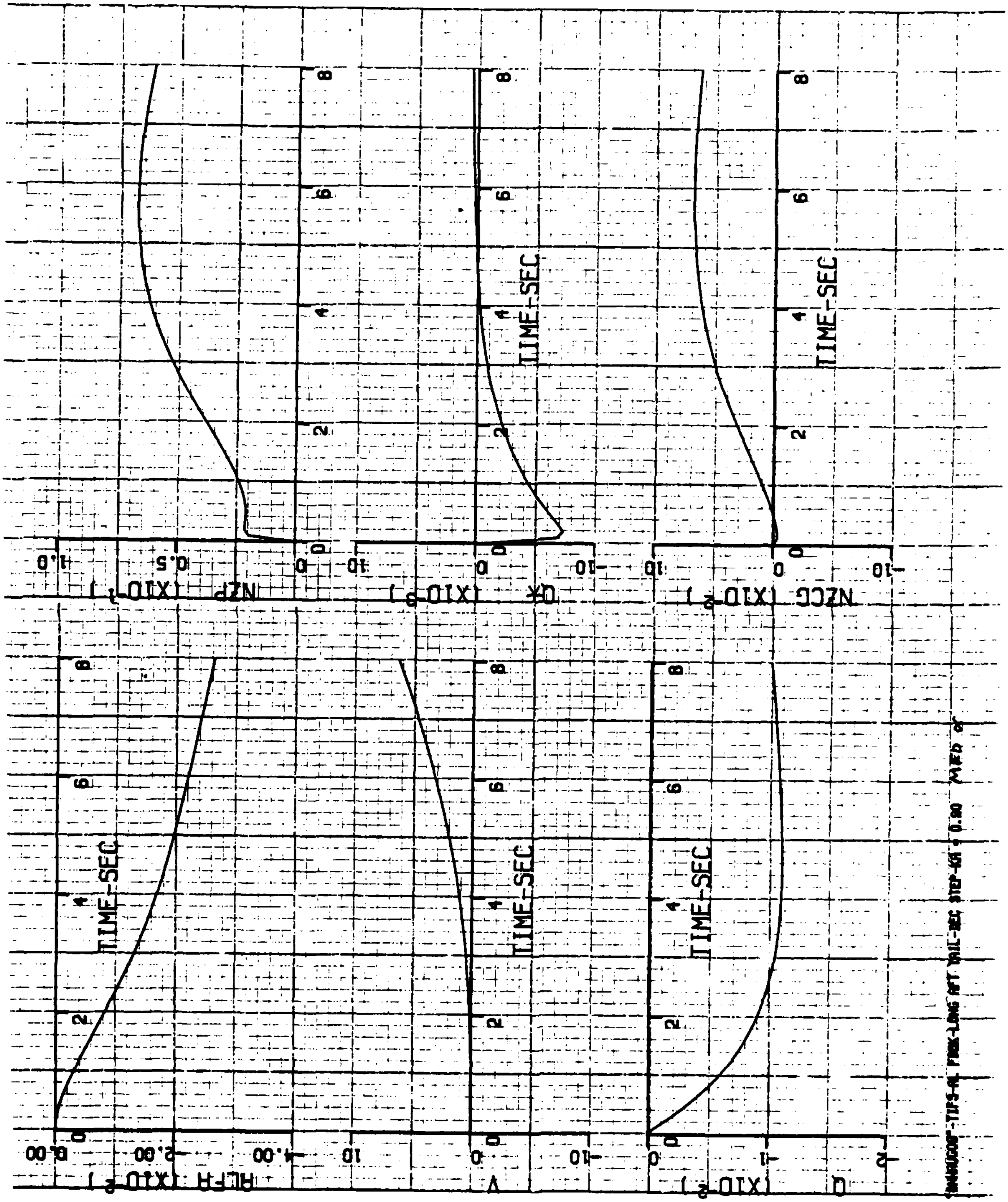
P — (p) — roll rate, rad/sec
R — (r) — yaw rate, rad/sec
BETA — (β) — sideslip, rad

	PHI — (ϕ)	— bank angle, rad
	P^* — ($\dot{p}$)	— roll acceleration, rad/sec
	R^* — ($\dot{r}$)	— yaw acceleration, rad/sec
	$NYCG$ — ($n_{y_{CG}}$)	— lateral acceleration at center of gravity, g's
$\tau_R = .87$ configurations	$NY50$, 70, 110	— lateral acceleration at nominal pilot height above stability axis (Z_{sp} = -18 ft) and X_{MP} = 50, 70, 110 ft, g's
	$NYHI$	— lateral acceleration at higher pilot station above stability axis (Z_{sp} = -36 ft) and X_{MP} = 110 ft for this configuration
$\tau_R = .44$ configurations	$NYP1$	— lateral acceleration at nominal pilot position height (Z_{sp} = -18 ft) and X_{MP} = 110 feet
	$NYP2$	— lateral acceleration at higher pilot station above stability axis (Z_{sp} = -36 ft) and X_{MP} = 110 feet

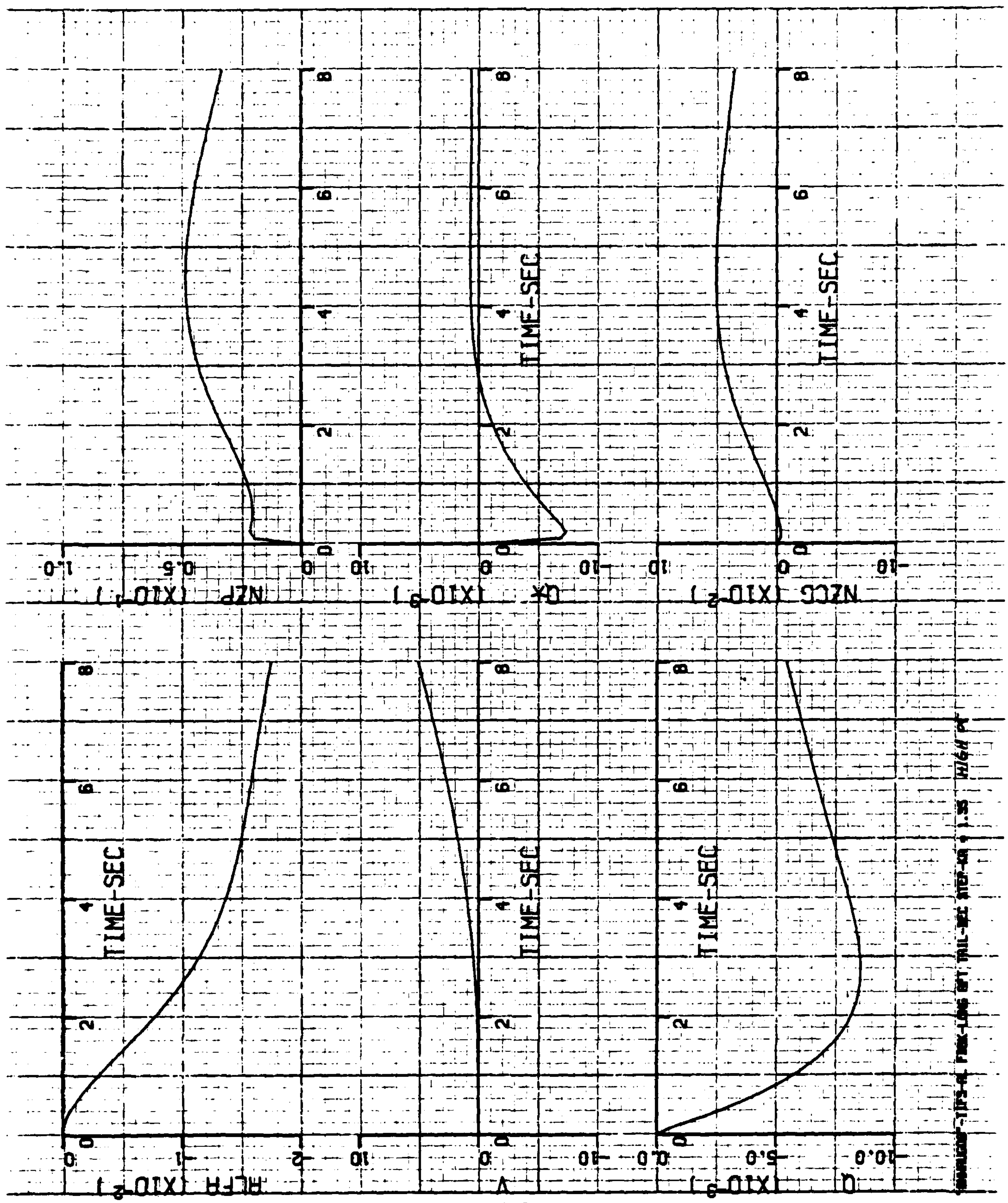
Note that scalings may change from one configuration to another.

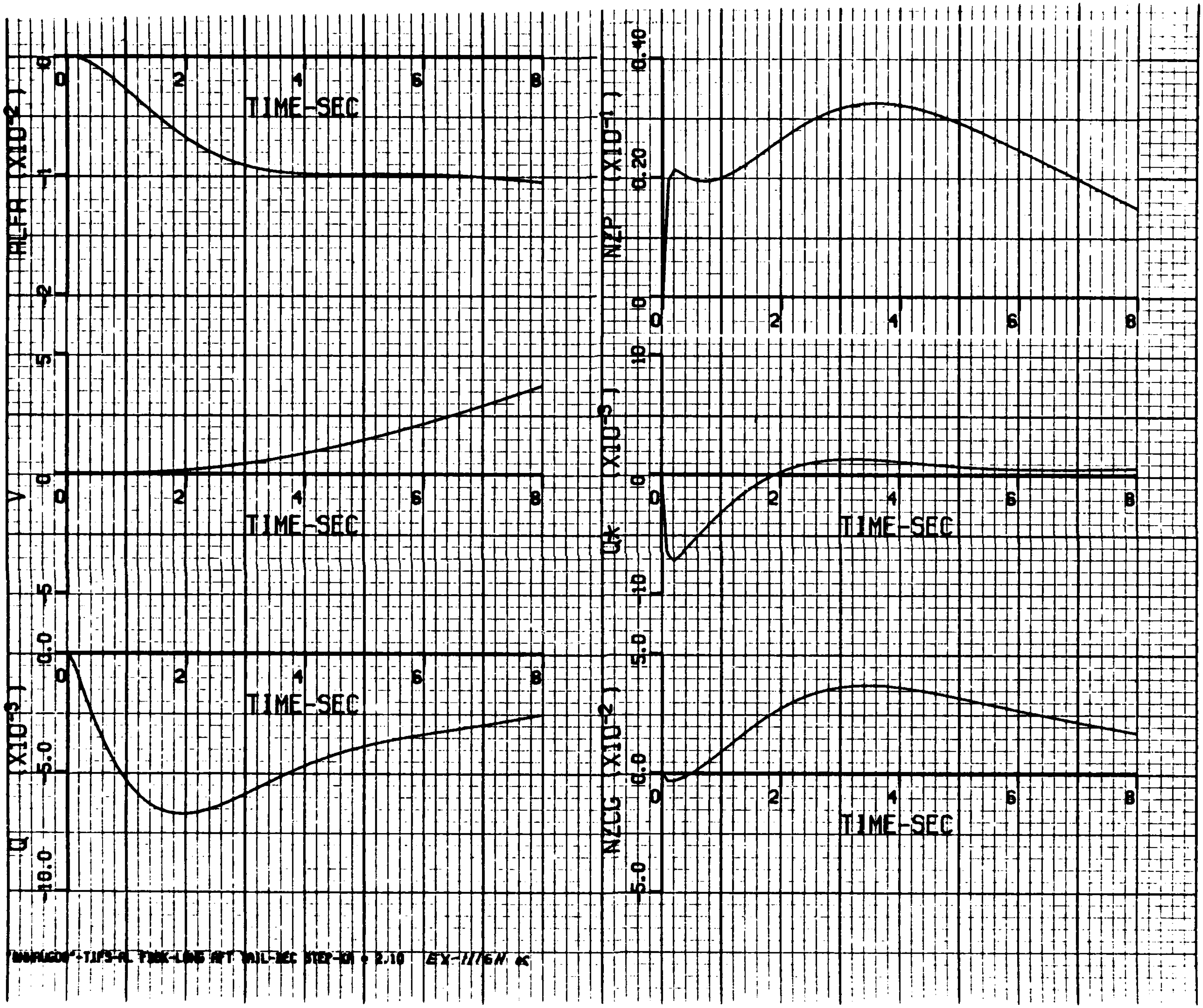

NZP
QX (XIO-3)
NZCG (XIO-1)
ALFA (XIO-2)
V
Q (XIO-2)
TIME-SEC

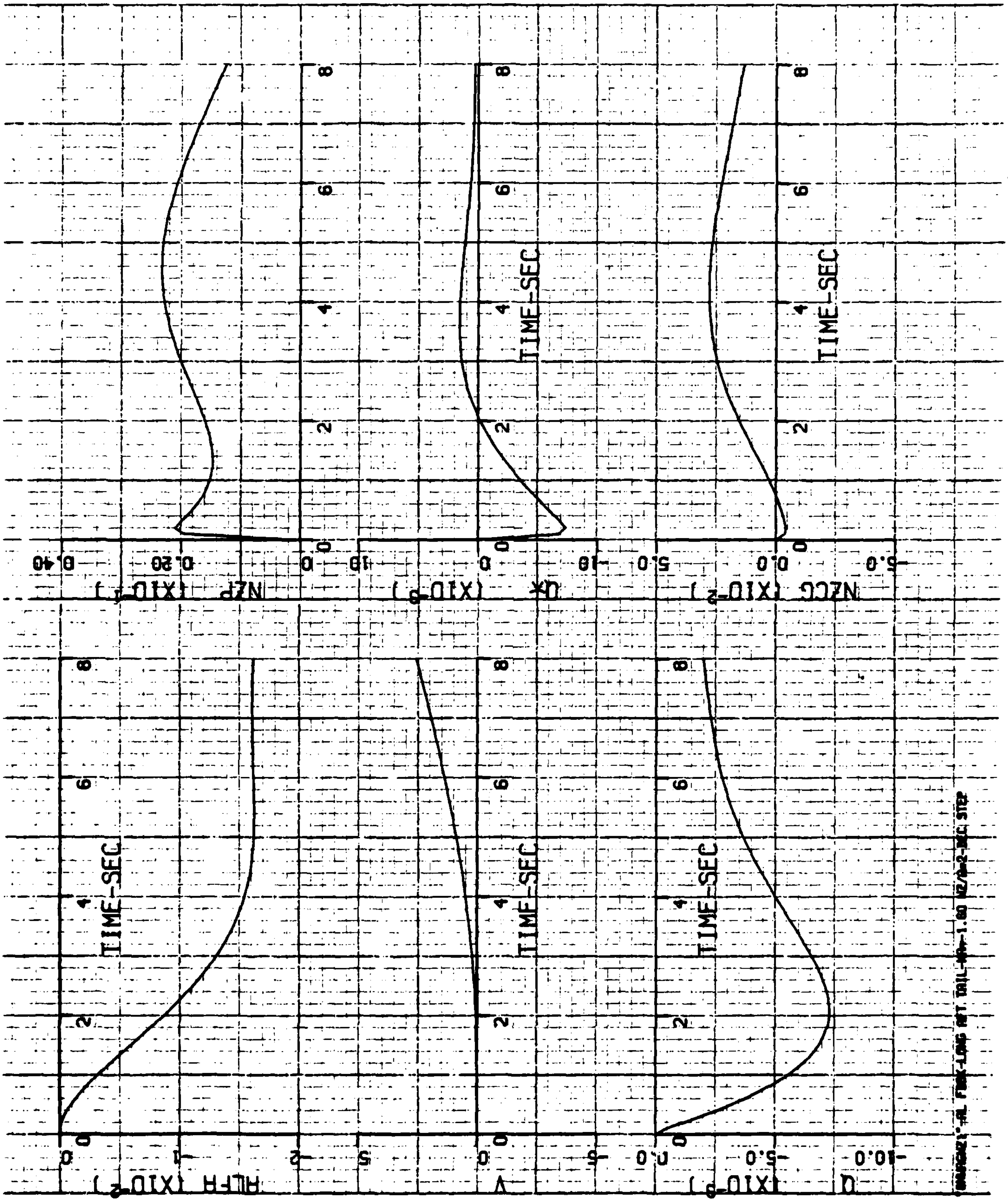

NZP (X10-1)
QK (X10-3)
NZCG (X10-2)
ALFA (X10-2)
V
Q (X10-2)
TIME-SEC

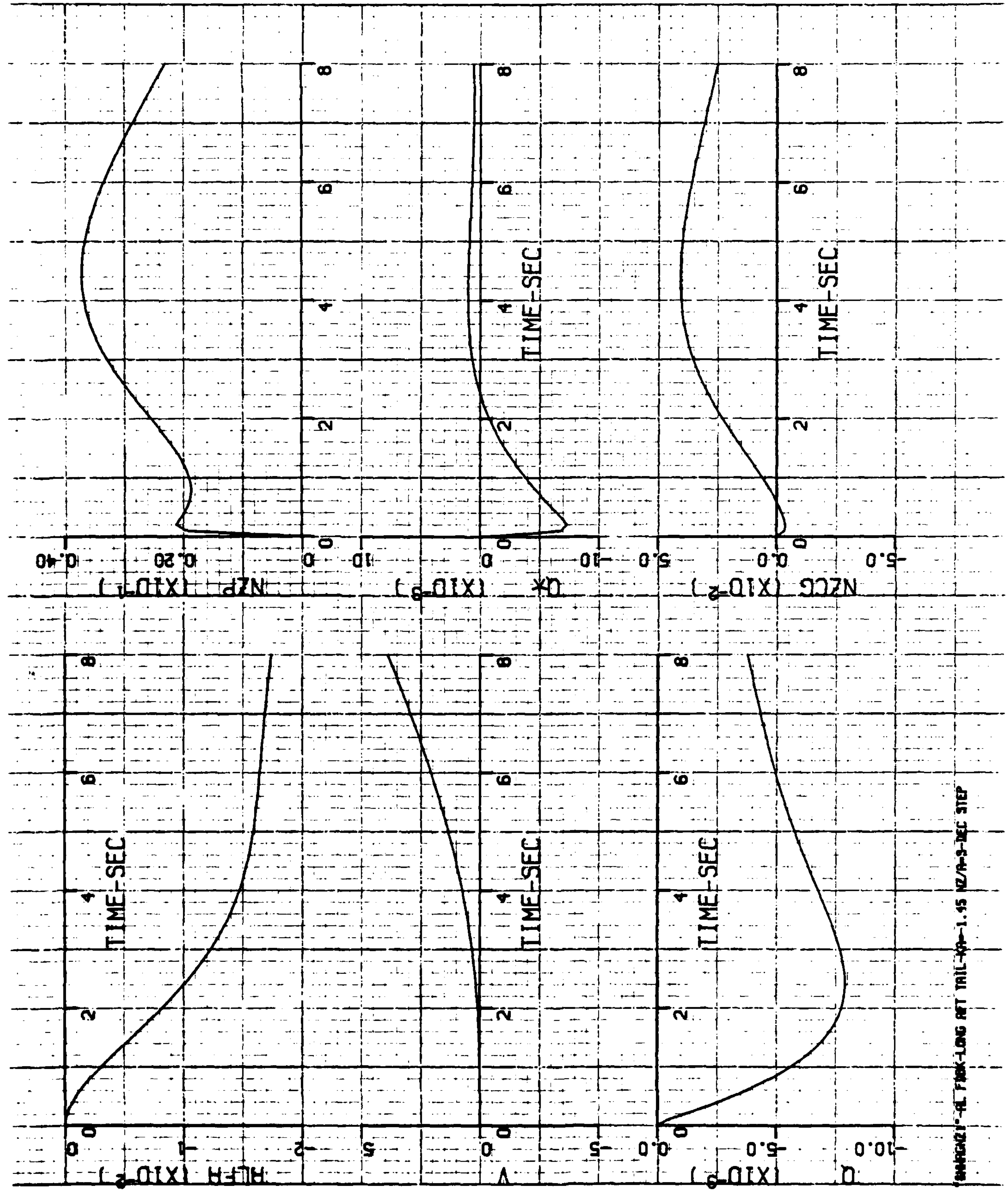


TIME-SEC
TIME-SEC
TIME-SEC
TIME-SEC
TIME-SEC
TIME-SEC
NZP
NZCG
ALFA
V
Q

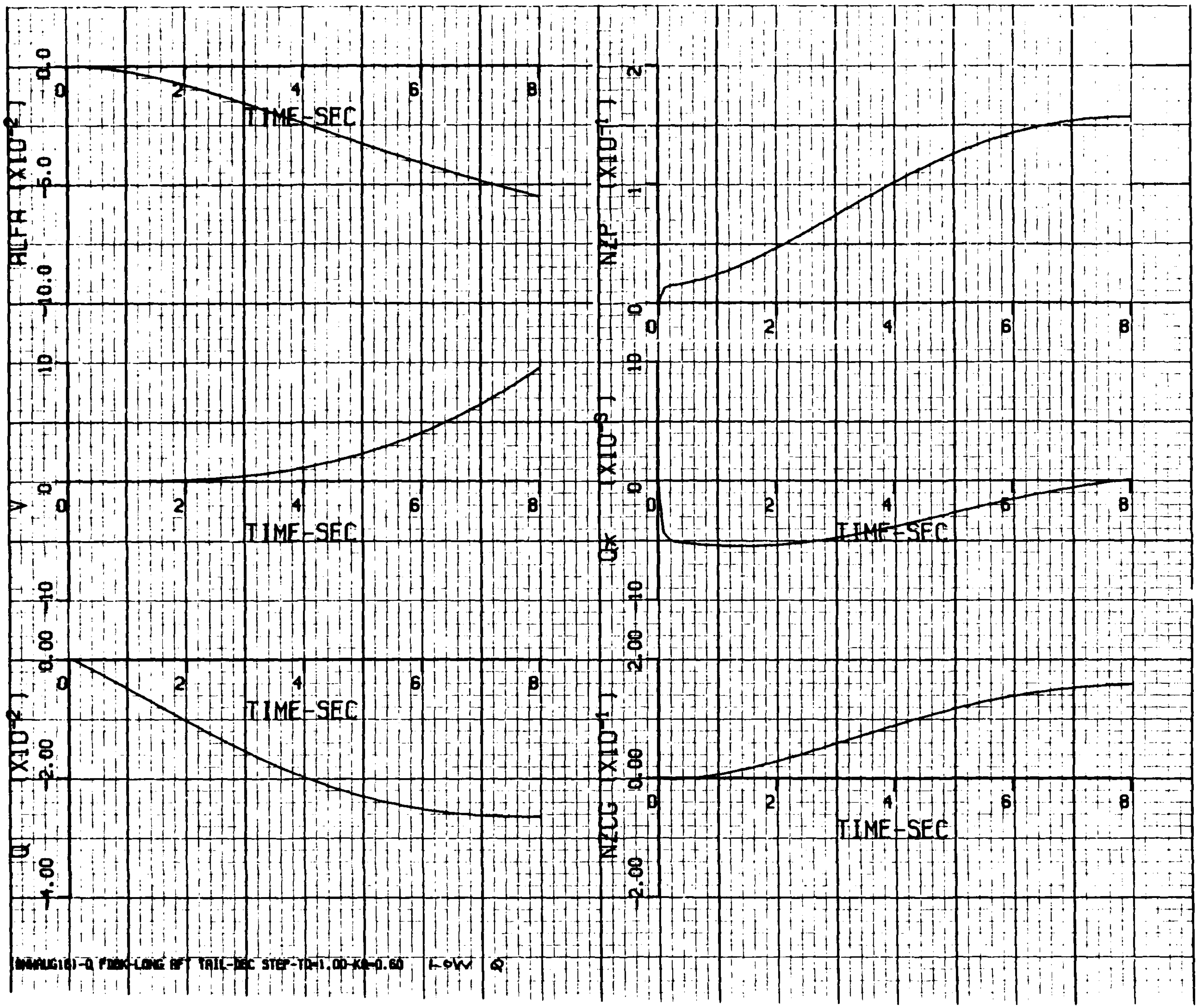

TIME-SEC
NZP
NZCG
ALFA
V
Q

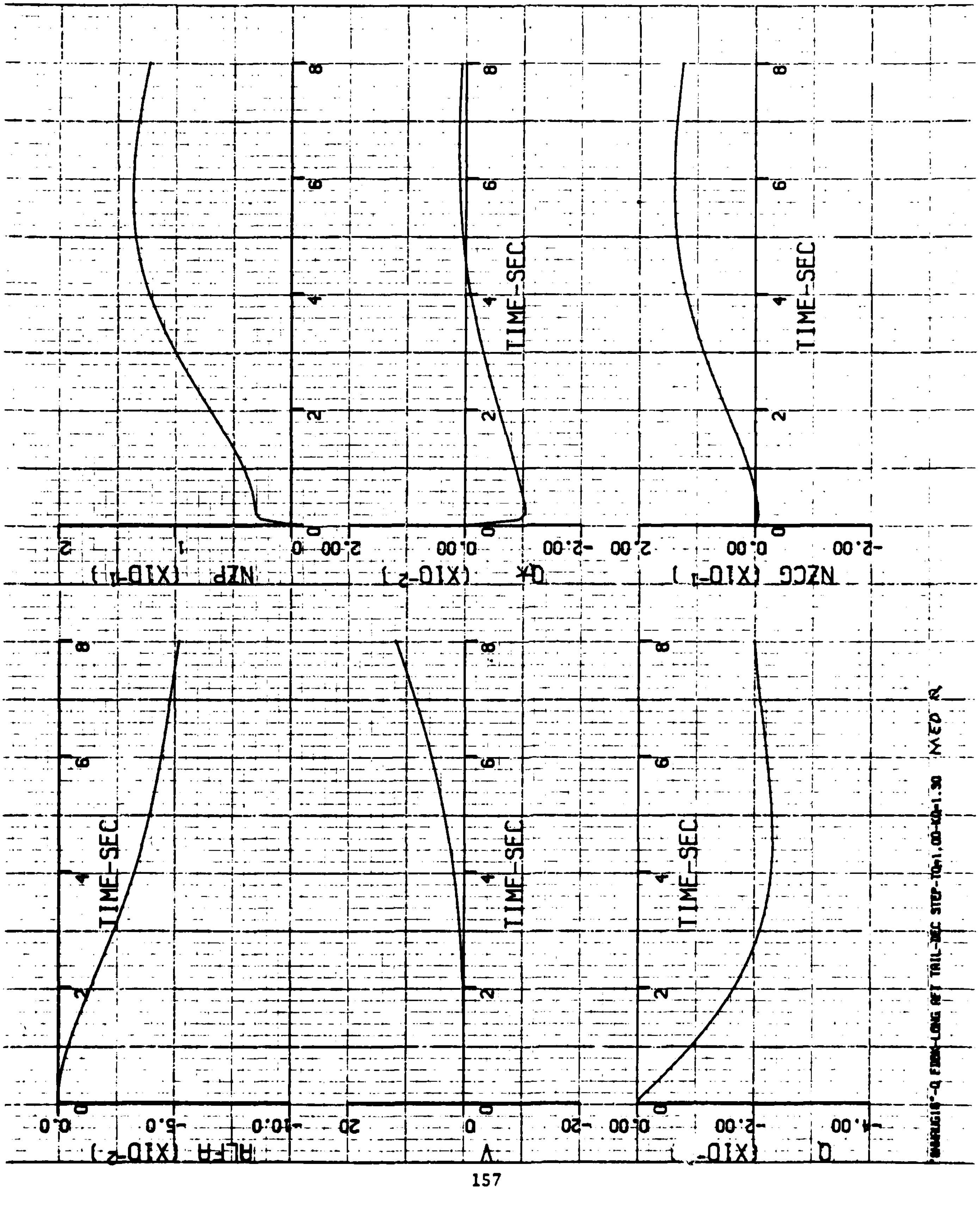

ALFA (X10^-2)
V
Q (X10^-3)
NZP (X10^-1)
Q* (X10^-3)
NZCG (X10^-2)
TIME-SEC
TIME-SEC
TIME-SEC
TIME-SEC
TIME-SEC
EX-1116N


ALFA (X10^-2)
V
Q (X10^-6)
NZP (X10^-1)
Q* (X10^-6)
NZCG (X10^-2)
TIME-SEC

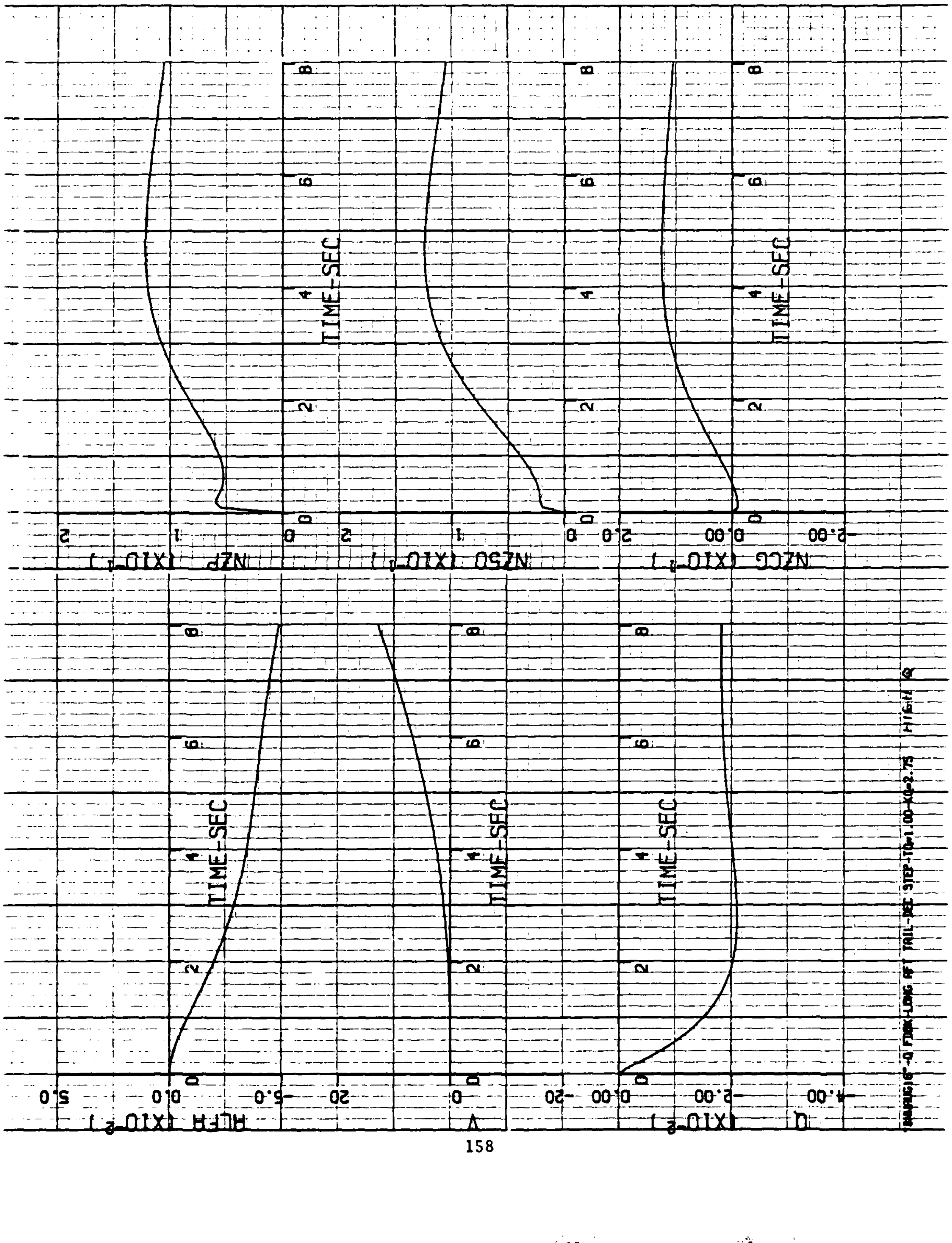


NZP (X10^-1)
Q* (X10^-3)
NZCG (X10^-2)
ALFA (X10^-2)
V
Q (X10^-3)
TIME-SEC

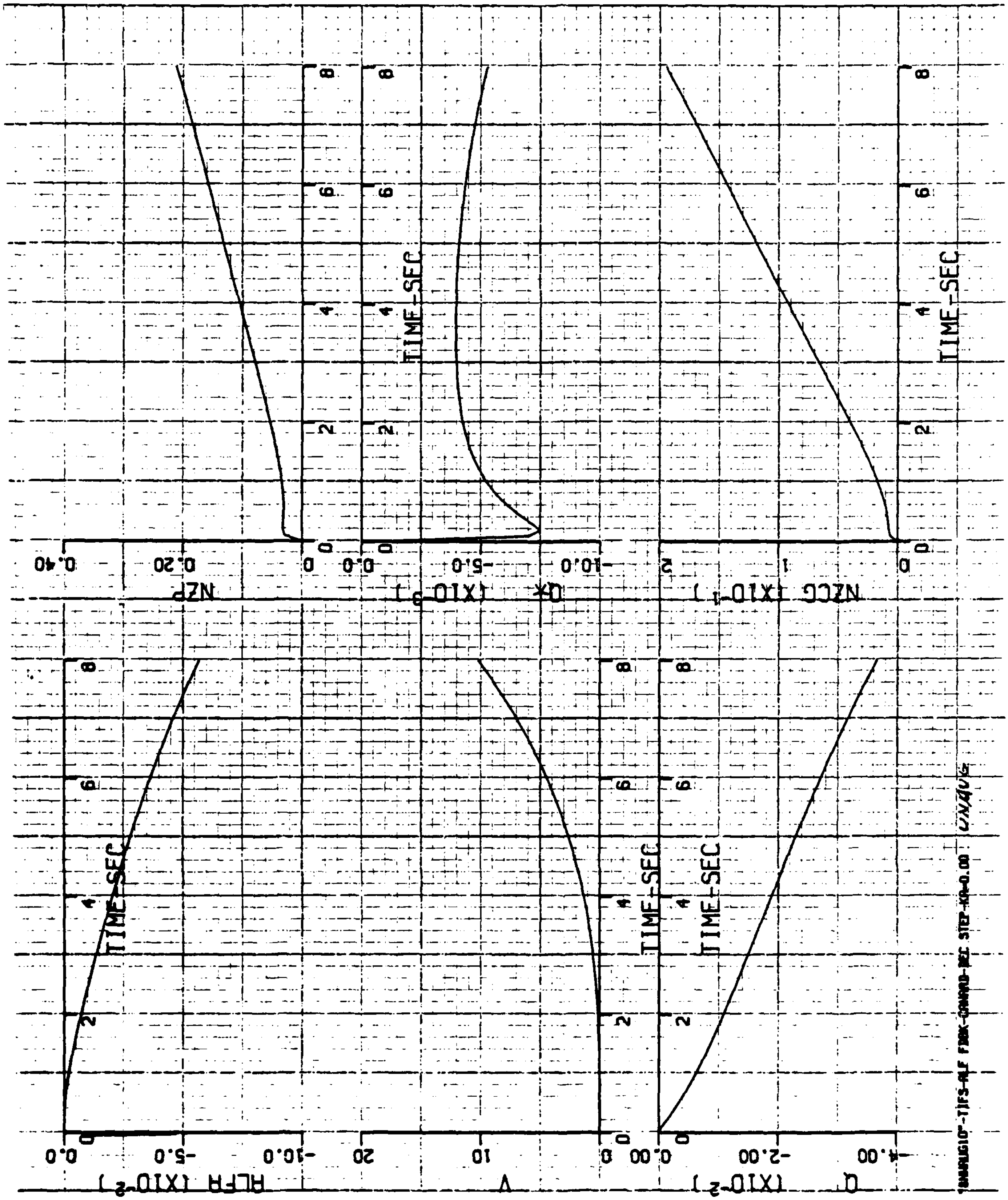

ALFA (X10^-2)
V
Q (X10^-2)
NZP (X10^-1)
Q* (X10^-3)
NZCG (X10^-1)
TIME-SEC
(NNNAUG18)-Q FDBK-LONG AFT TAIL-DEC STEP-TQ=1.00-KQ=0.60



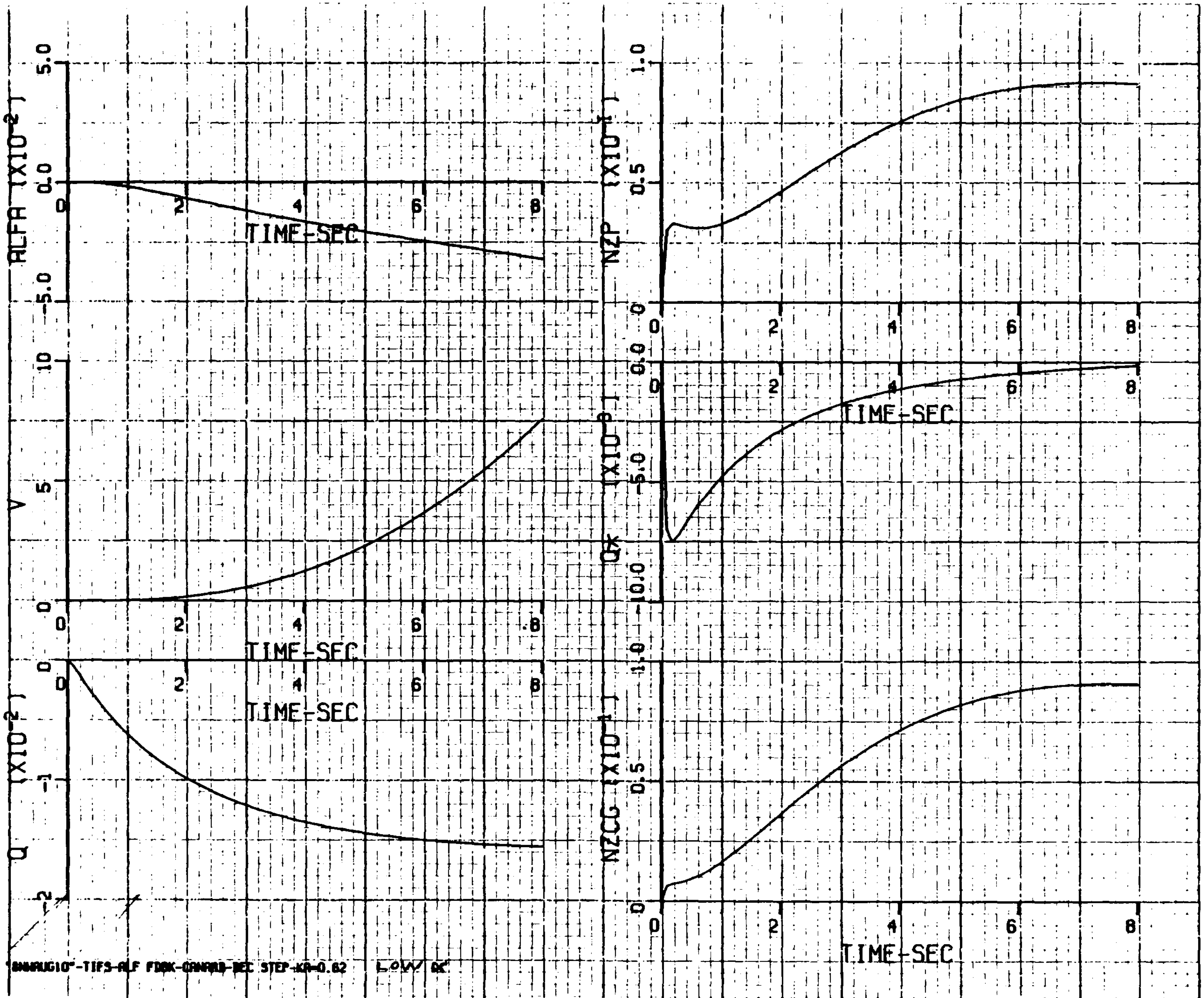
NZP (X10-1)
Q* (X10-2)
NZCG (X10-1)
ALFA (X10-2)
V
Q (X10-)
TIME-SEC
MED R

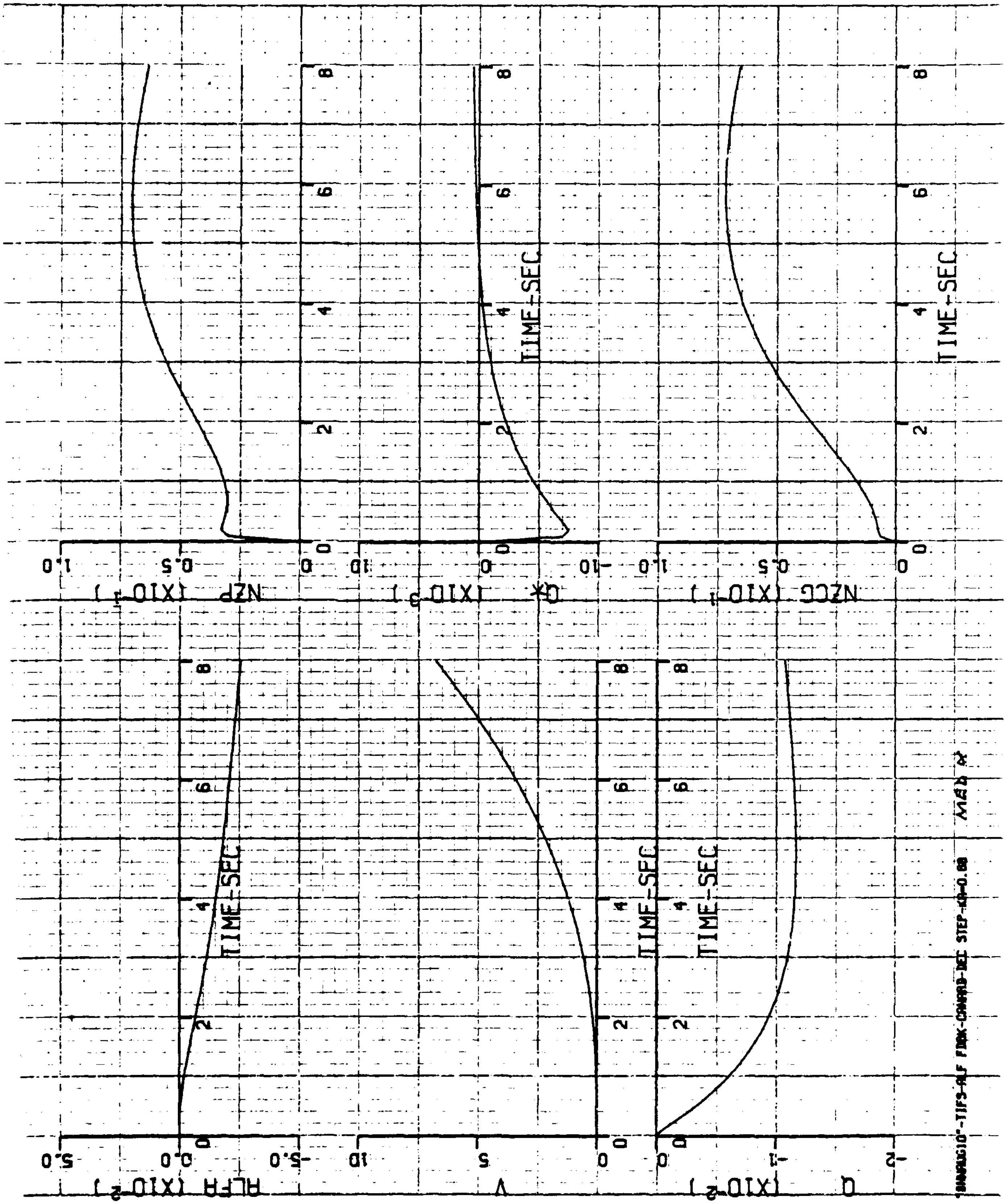


NZP (X10^-1)
NZ50 (X10^-1)
NZCG (X10^-1)
ALFA (X10^-2)
V
Q (X10^-2)
TIME-SEC
TIME-SEC
TIME-SEC
TIME-SEC
TIME-SEC
HIGH Q

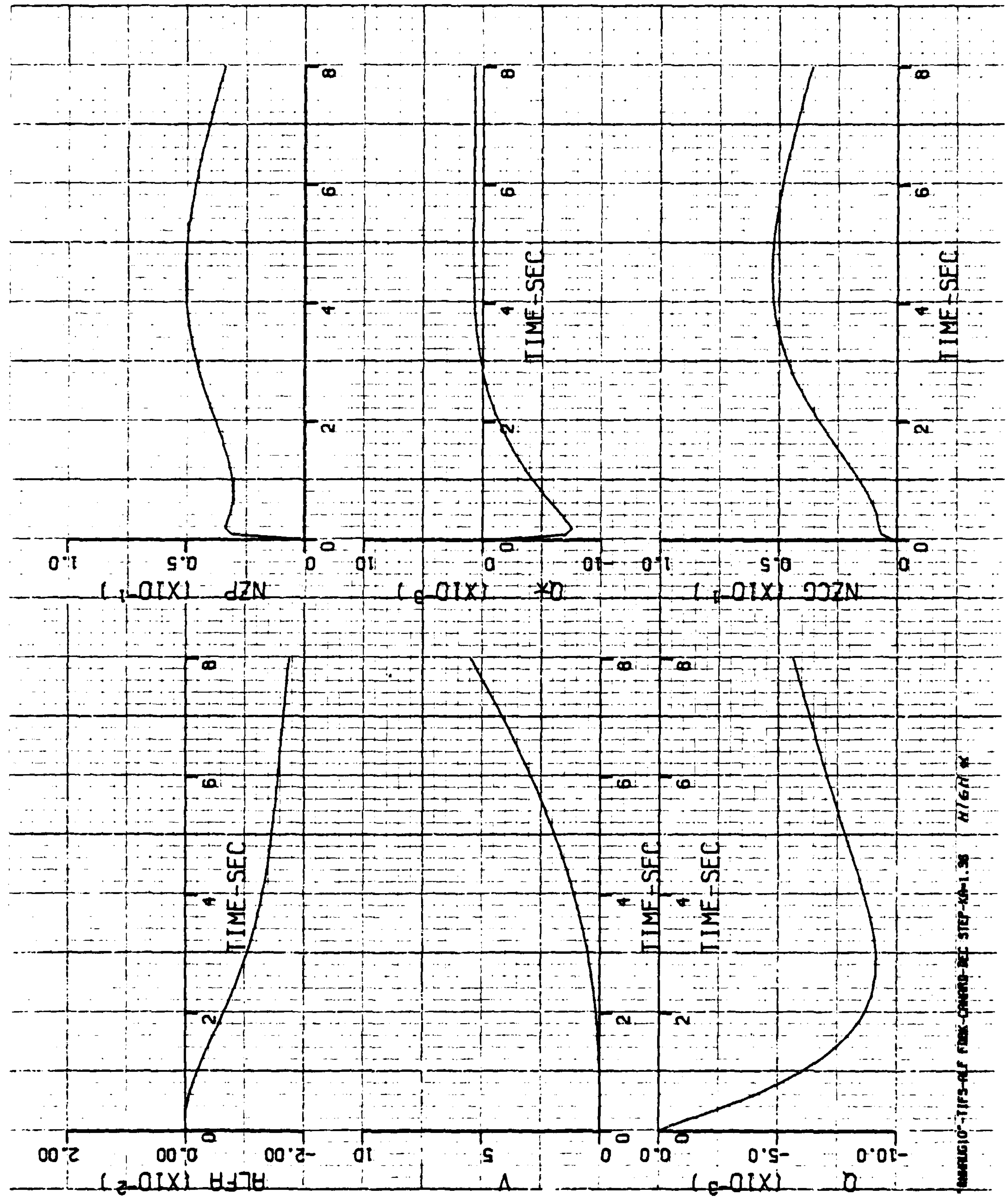


NZP
QX (XIO-3)
NZCG (XIO-1)
ALFA (XIO-2)
V
Q (XIO-2)
TIME-SEC

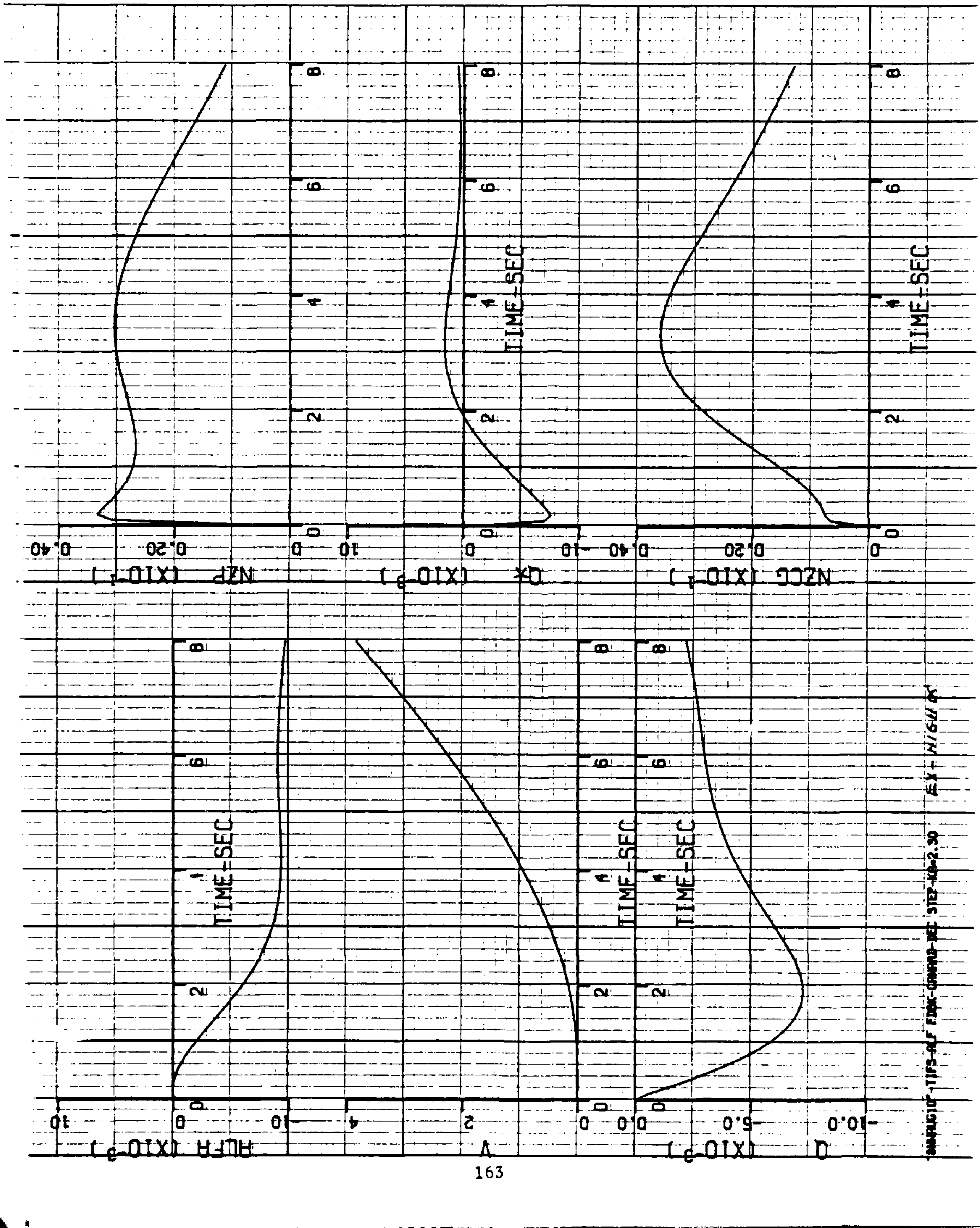

ALFA (X10^-2)
V
Q (X10^-2)
NZP (X10^-1)
Q* (X10^-3)
NZCG (X10^-1)
TIME-SEC
TIFS-ALF FDBK-CANARD-DEC STEP-KA=0.62

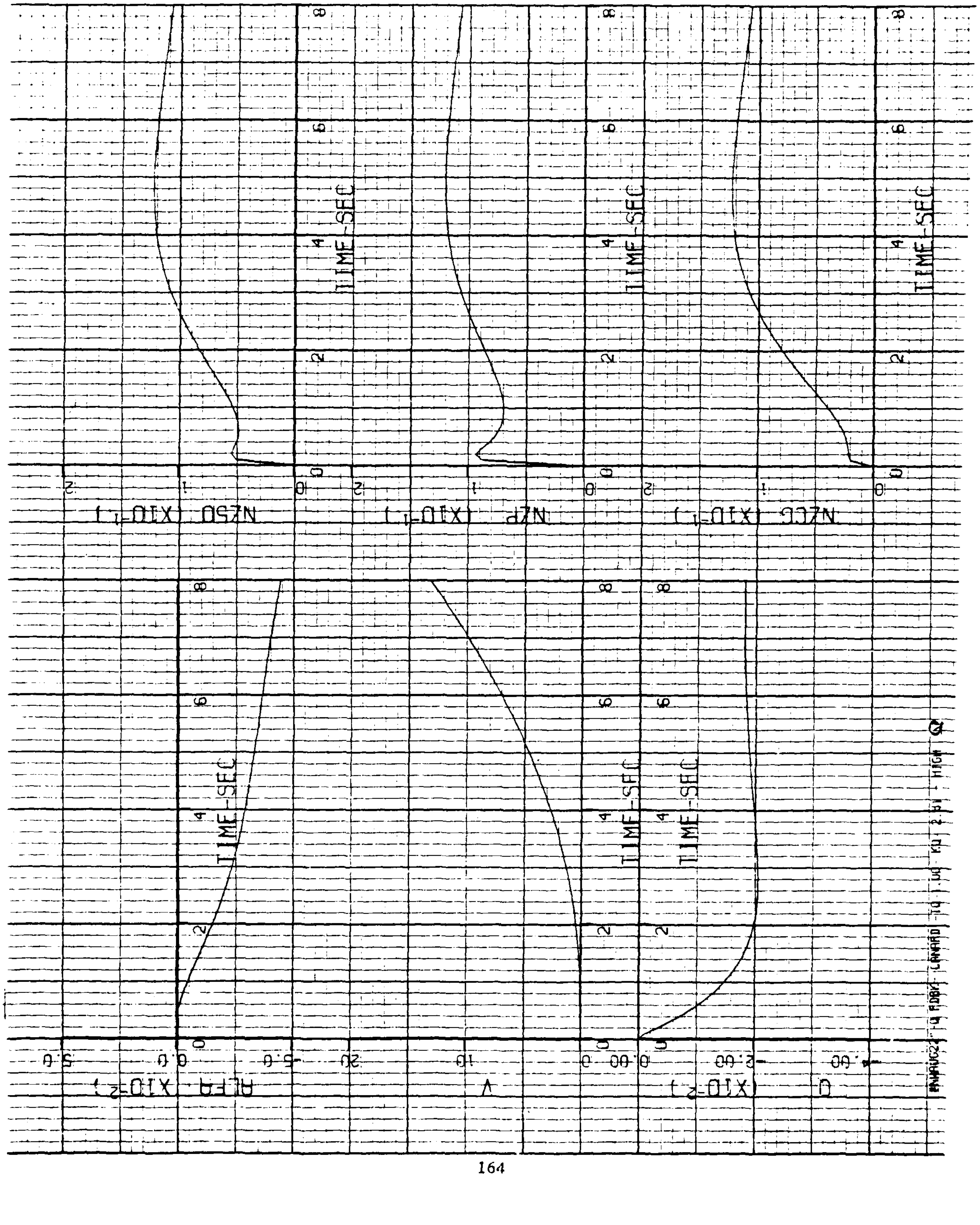


NZP (X10-1)
Q* (X10-3)
NZCG (X10-1)
ALFA (X10-2)
V
Q (X10-2)
TIME-SEC

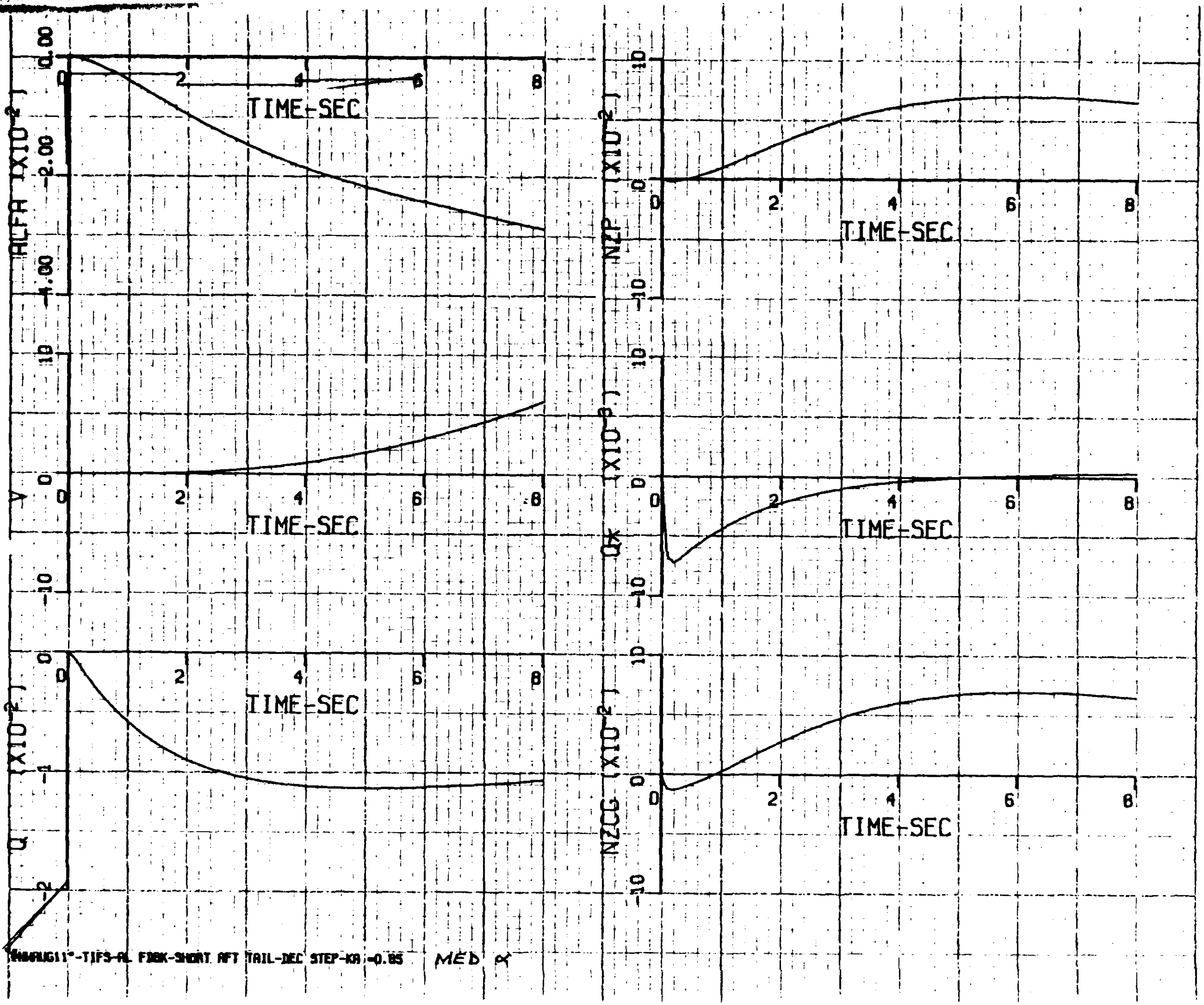


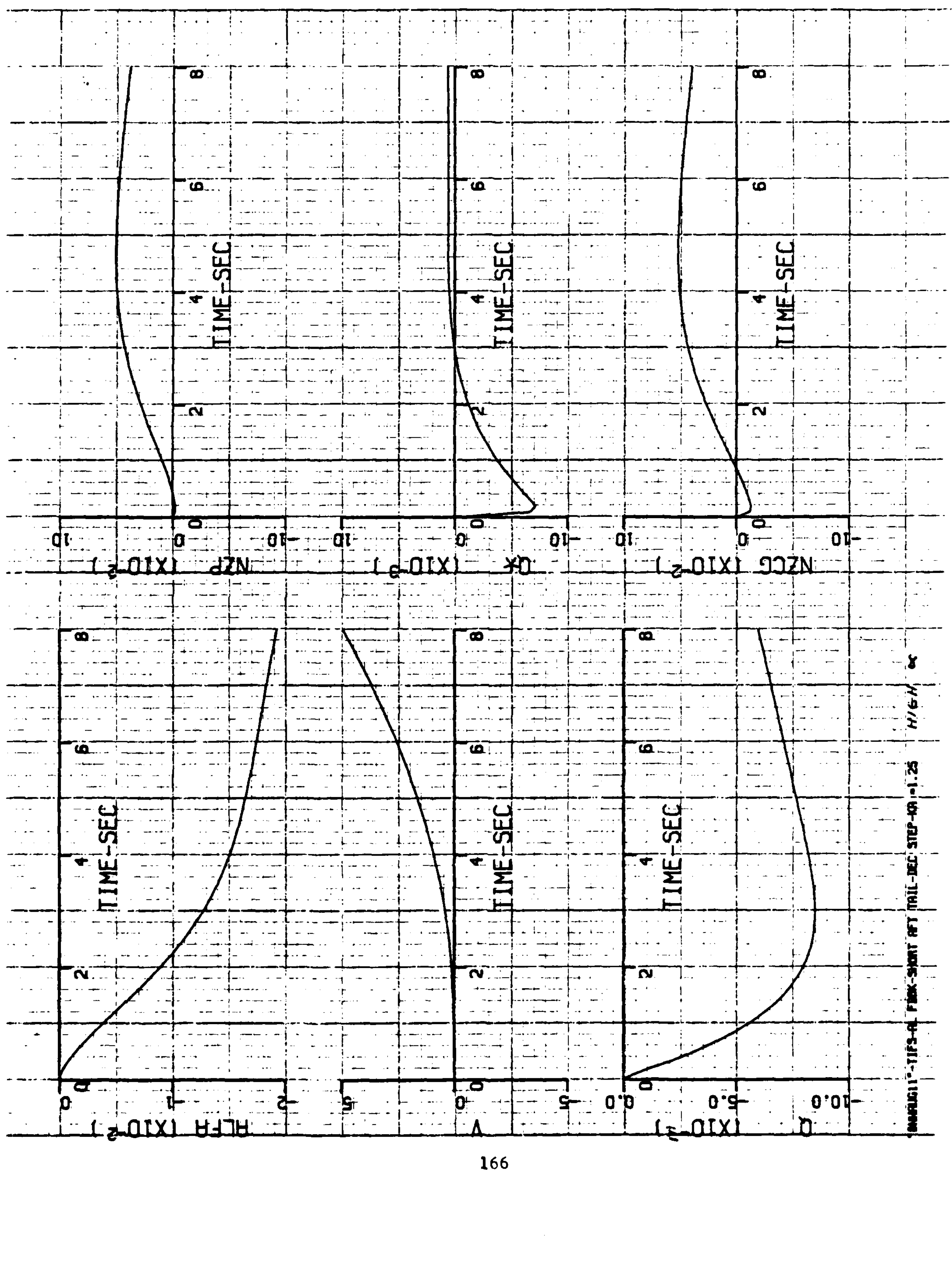
ALFA (X10^-2)
V
Q (X10^-3)
NZP (X10^-1)
Q* (X10^-3)
NZCG (X10^-1)
TIME-SEC

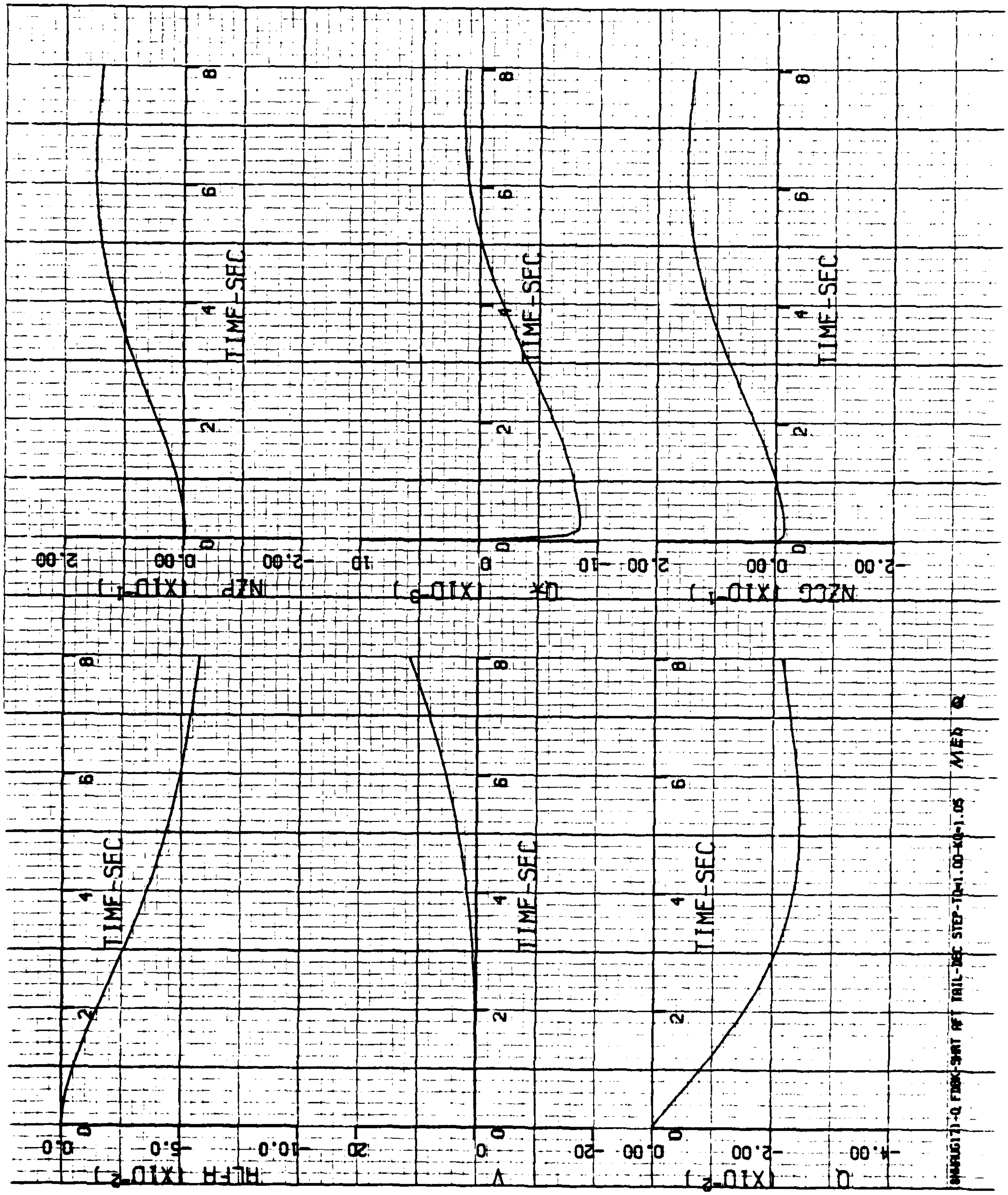

TIME-SEC
NZP (X10-1)
Q* (X10-3)
NZCG (X10-1)
ALFA (X10-3)
V
Q (X10-3)

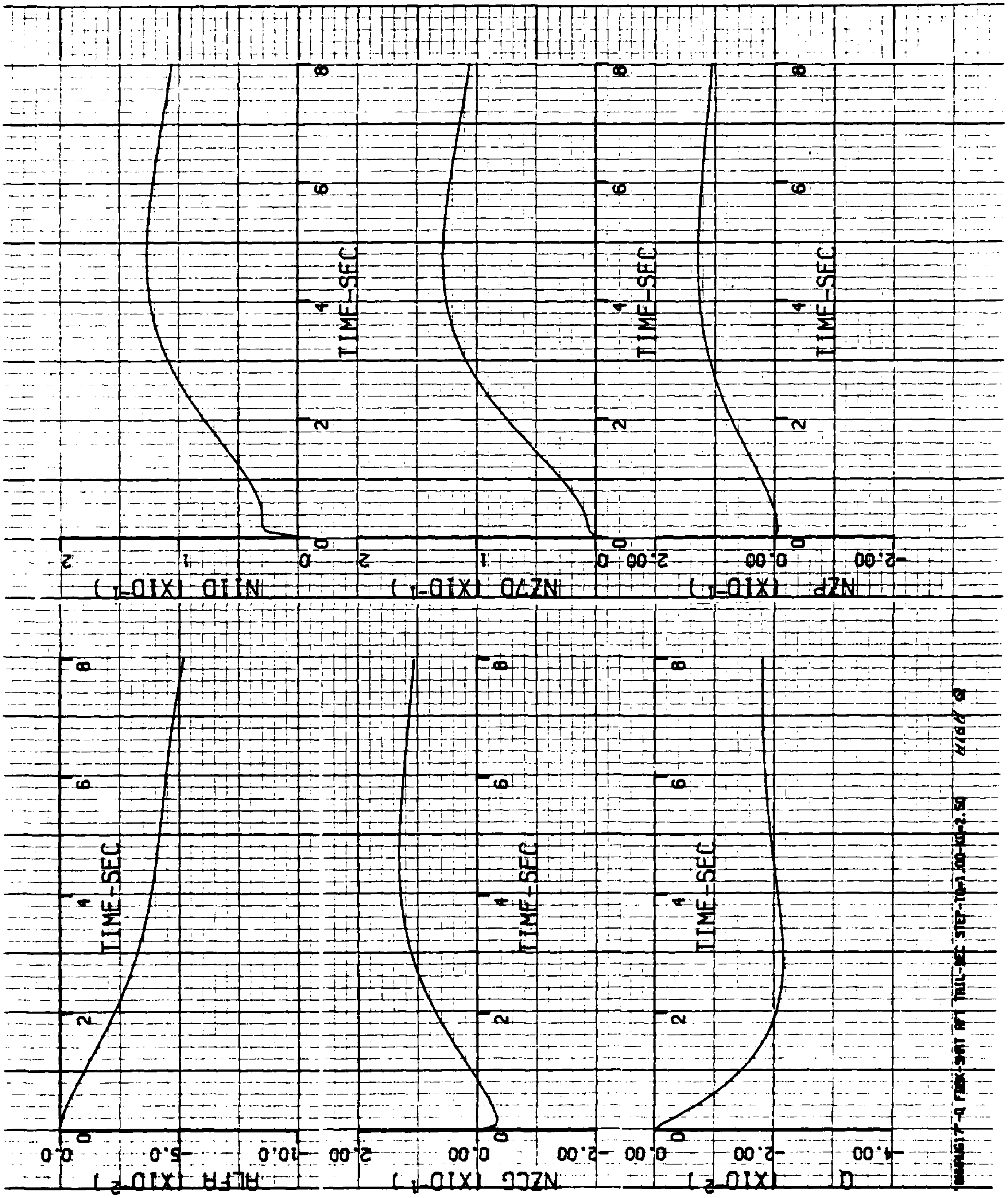


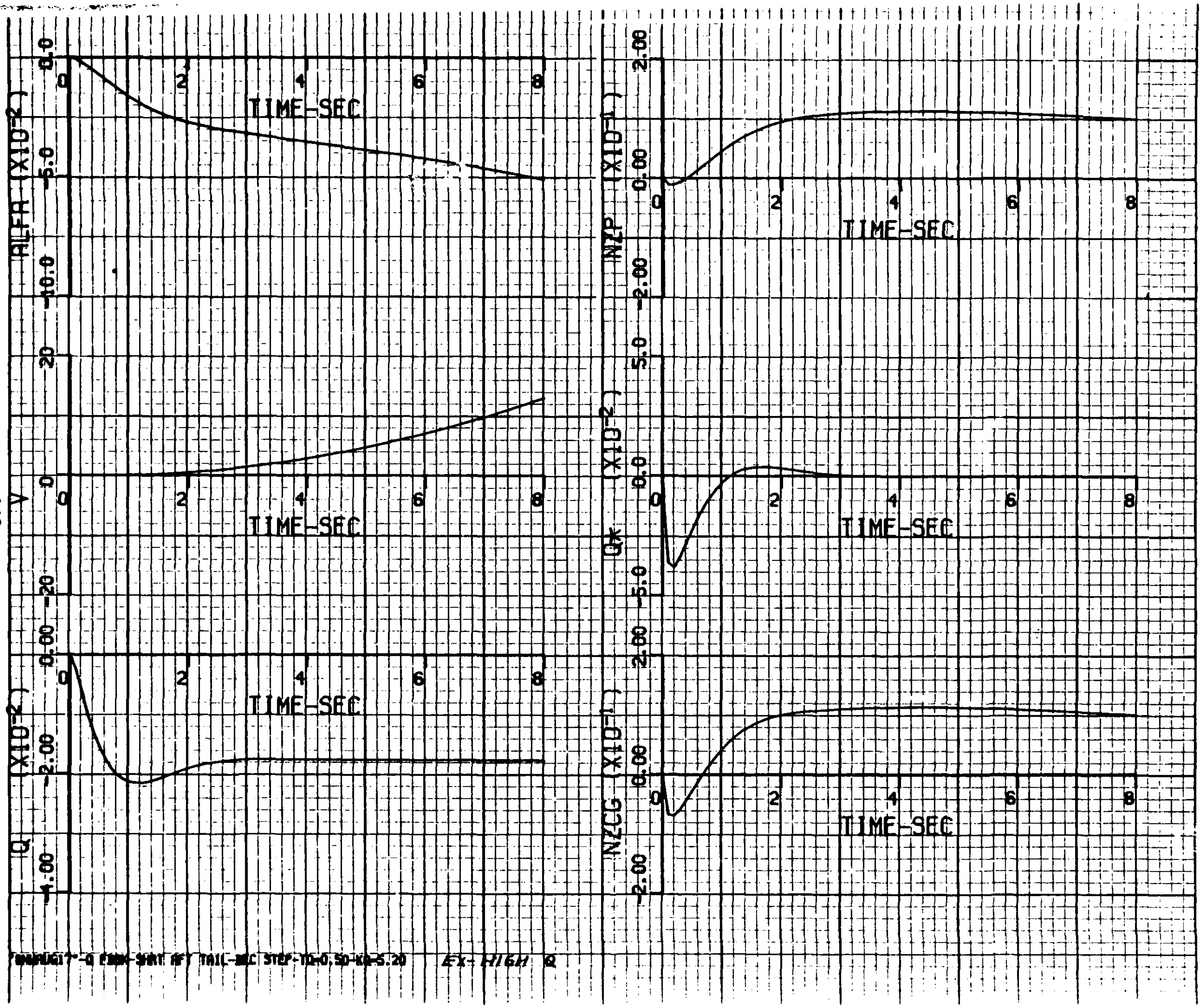
TIME-SEC
NZSO (X10⁻¹)
NZP (X10⁻¹)
NZCC (X10⁻¹)
ALFA (X10⁻²)
V
Q (X10⁻²)

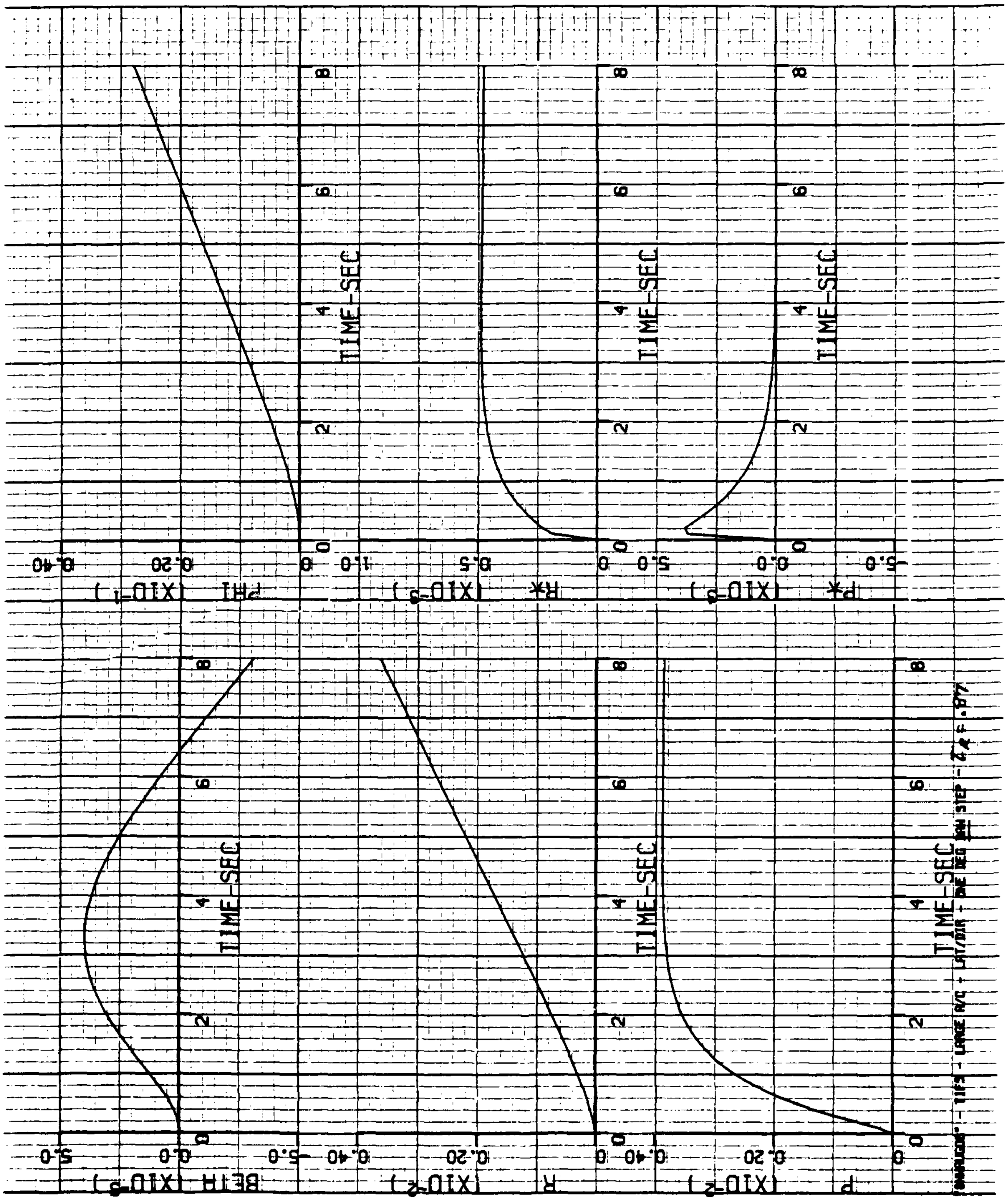

ALFA (X10^2)
0.00
-2.00
-4.00
TIME-SEC
V
10
0
-10
TIME-SEC
Q (X10^2)
0
-1
-2
TIME-SEC
NZP (X10^2)
10
0
-10
TIME-SEC
QK (X10^3)
10
0
-10
TIME-SEC
NZCG (X10^2)
10
0
-10
TIME-SEC
0
2
4
6
8
-TIFS-AL FDBK-SHORT AFT TAIL-DEC STEP-KA=-0.85
MED α


ALFA (X10^-2)
V
Q (X10^-1)
NZP (X10^-2)
Q* (X10^-3)
NZCG (X10^-2)
TIME-SEC
FDBK-SHORT AFT TAIL-DEC STEP-KQ =1.25
HIGH

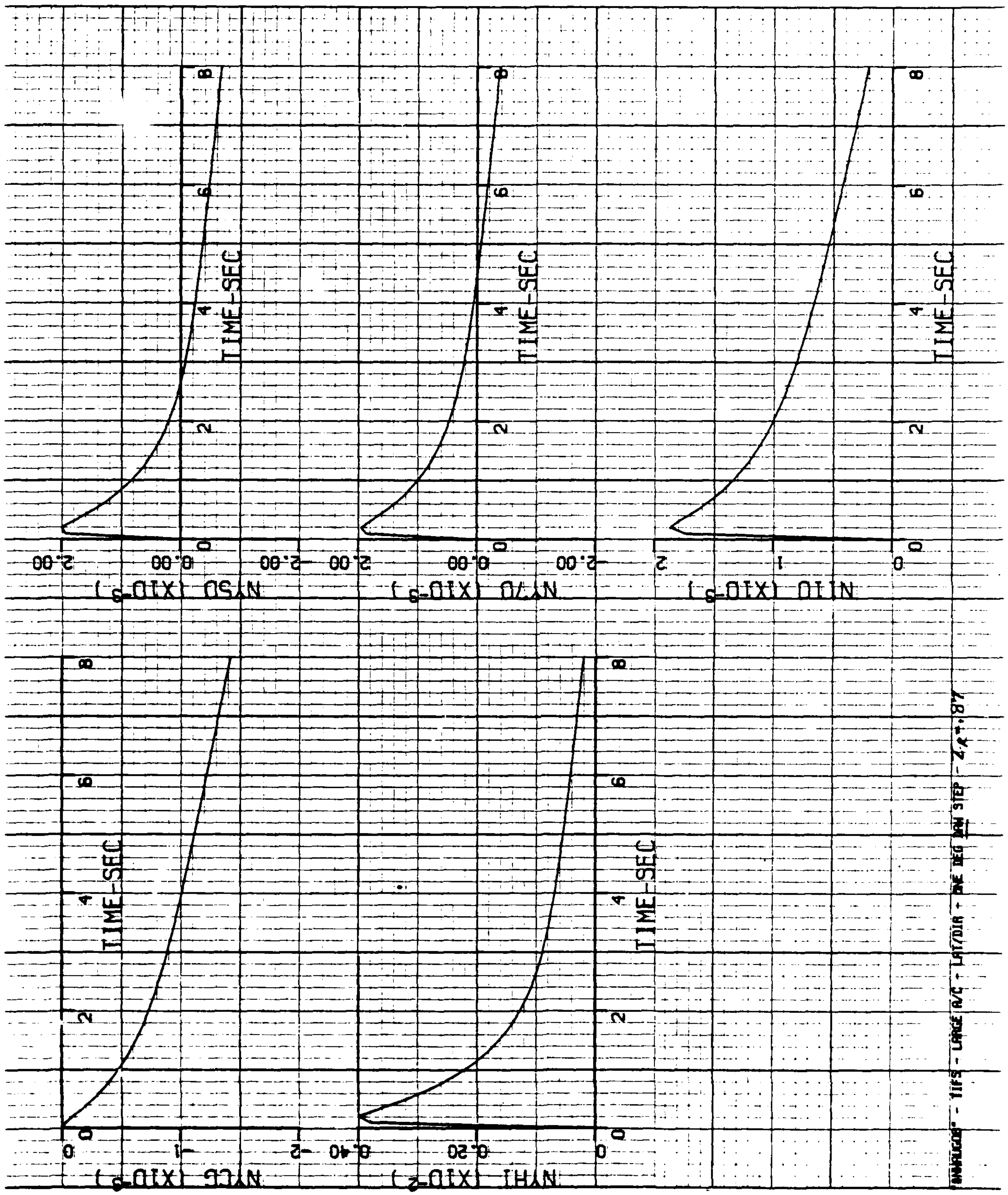

ALFA (X10^-2)
V
Q (X10^-2)
NZP (X10^-1)
Q* (X10^-3)
NZCG (X10^-1)
TIME-SEC
Q FDBK-SHRT AFT TAIL-DEC STEP-TQ=1.00-KQ=1.05


ALFA (X10^-2)
NZCG (X10^-1)
Q (X10^-2)
NZ7D (X10^-1)
NZP (X10^-1)
TIME-SEC

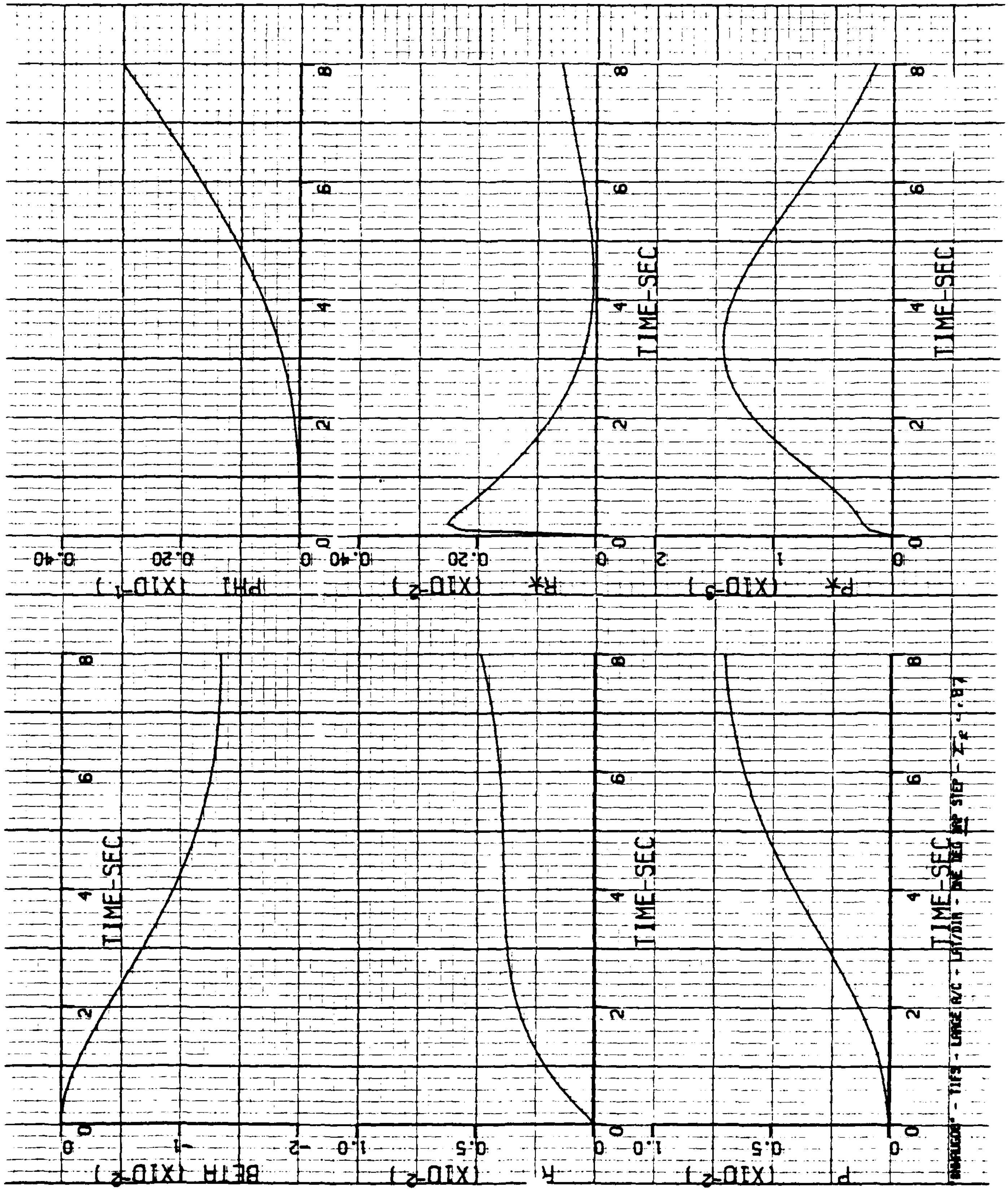

ALFA (X10^-2)
V
Q (X10^-2)
NZP (X10^-1)
Q* (X10^-2)
NZCG (X10^-1)
TIME-SEC
EX- HIGH Q



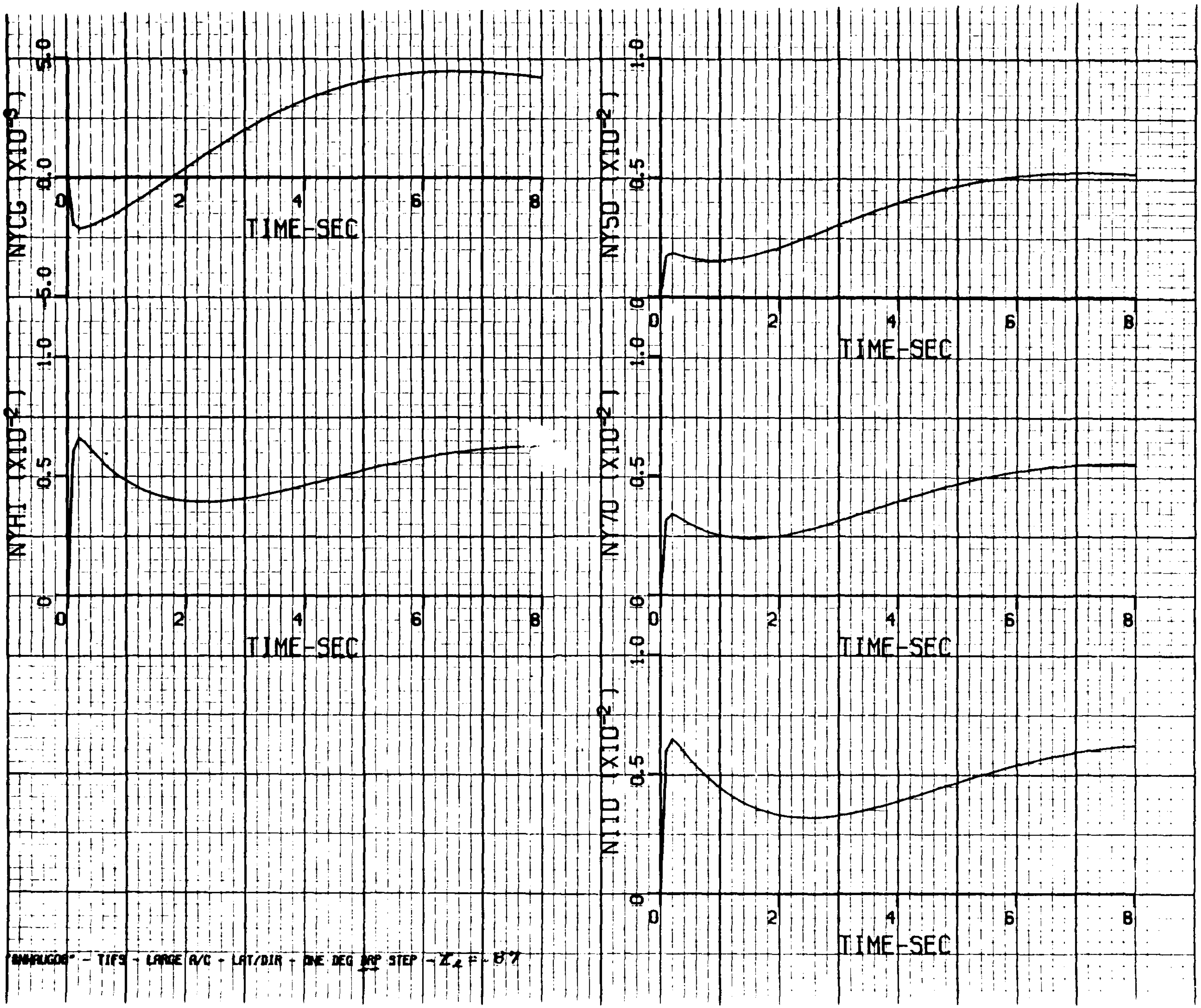
PHI (X10-)
R* (X10-)
P* (X10-)
BETA (X10-)
R (X10-)
P (X10-)
TIME-SEC
TIFS - LARGE A/C - LAT/DIR - ONE DEG
STEP

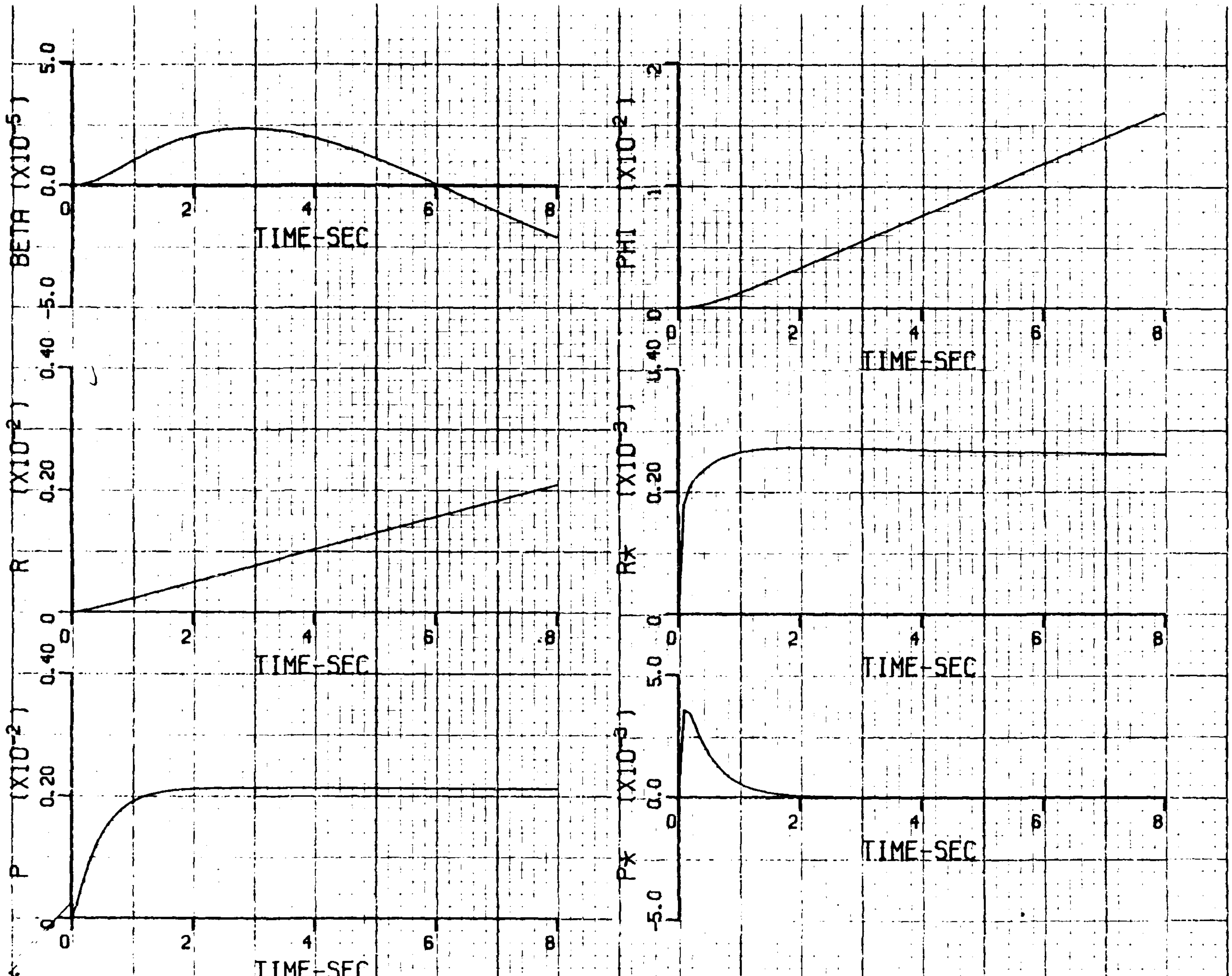


TIME-SEC
TIME-SEC
TIME-SEC
TIME-SEC
TIME-SEC

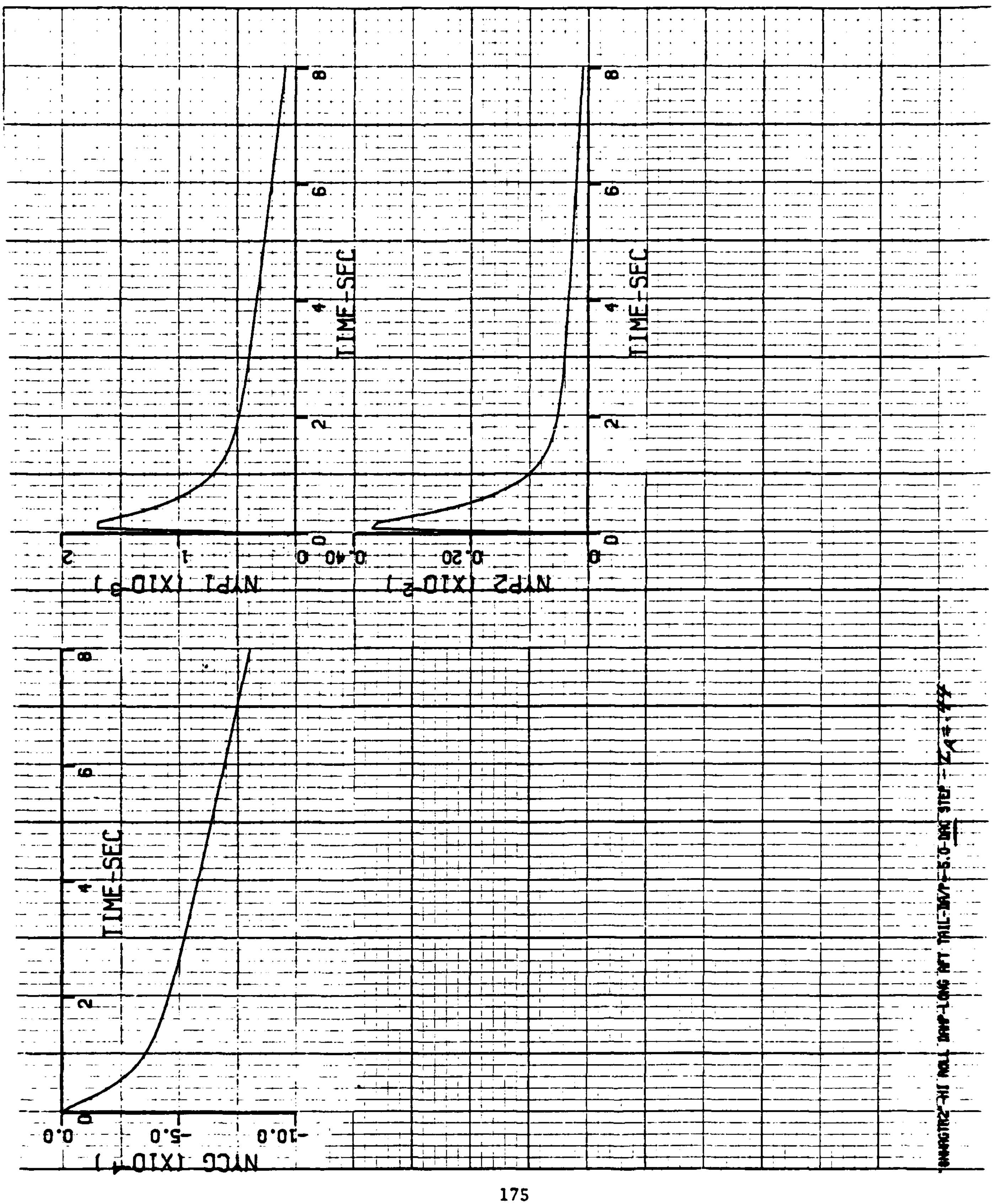


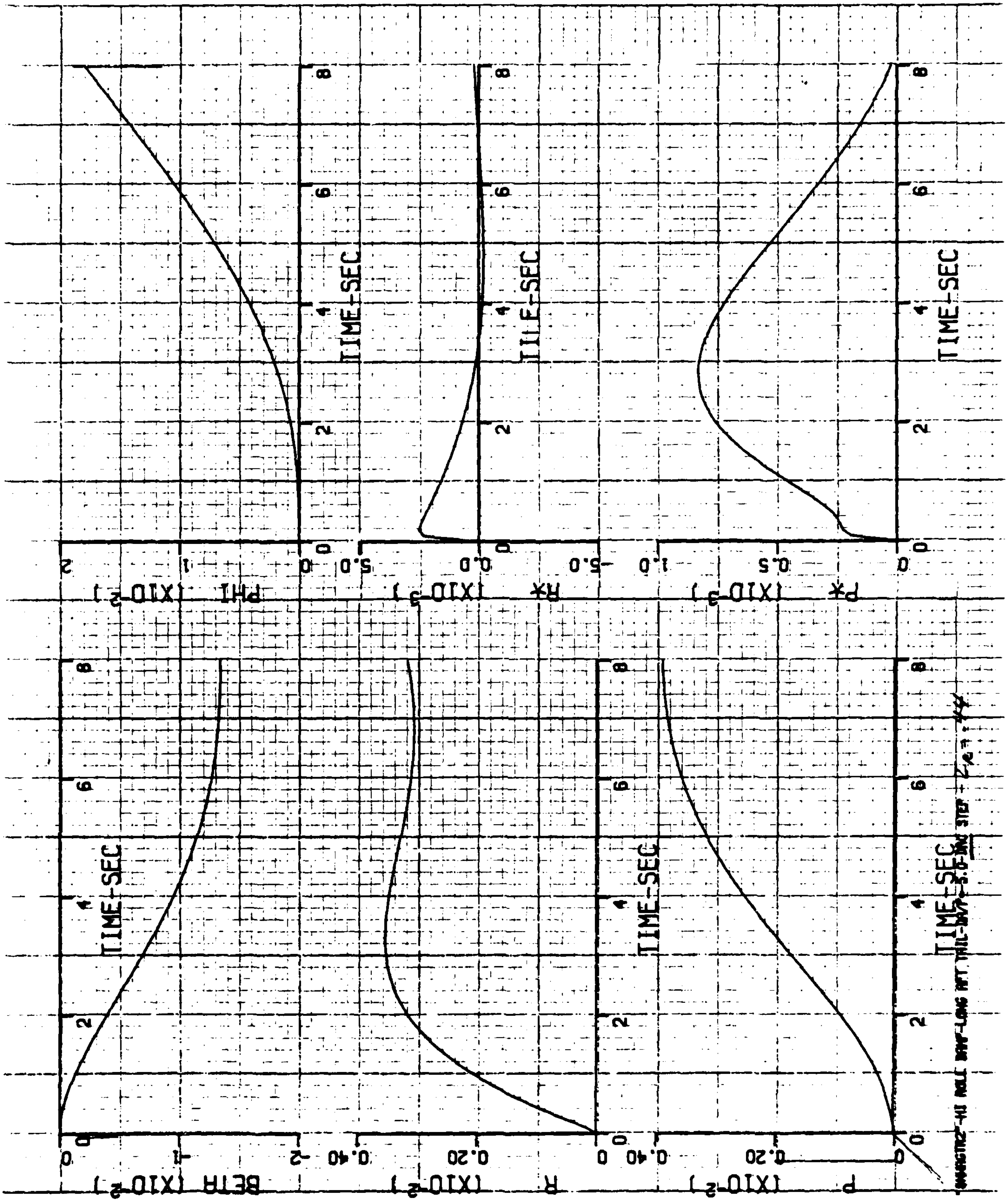
PHI (X10-1)
R* (X10-2)
P* (X10-3)
BETA (X10-2)
R (X10-2)
P (X10-2)
TIME-SEC

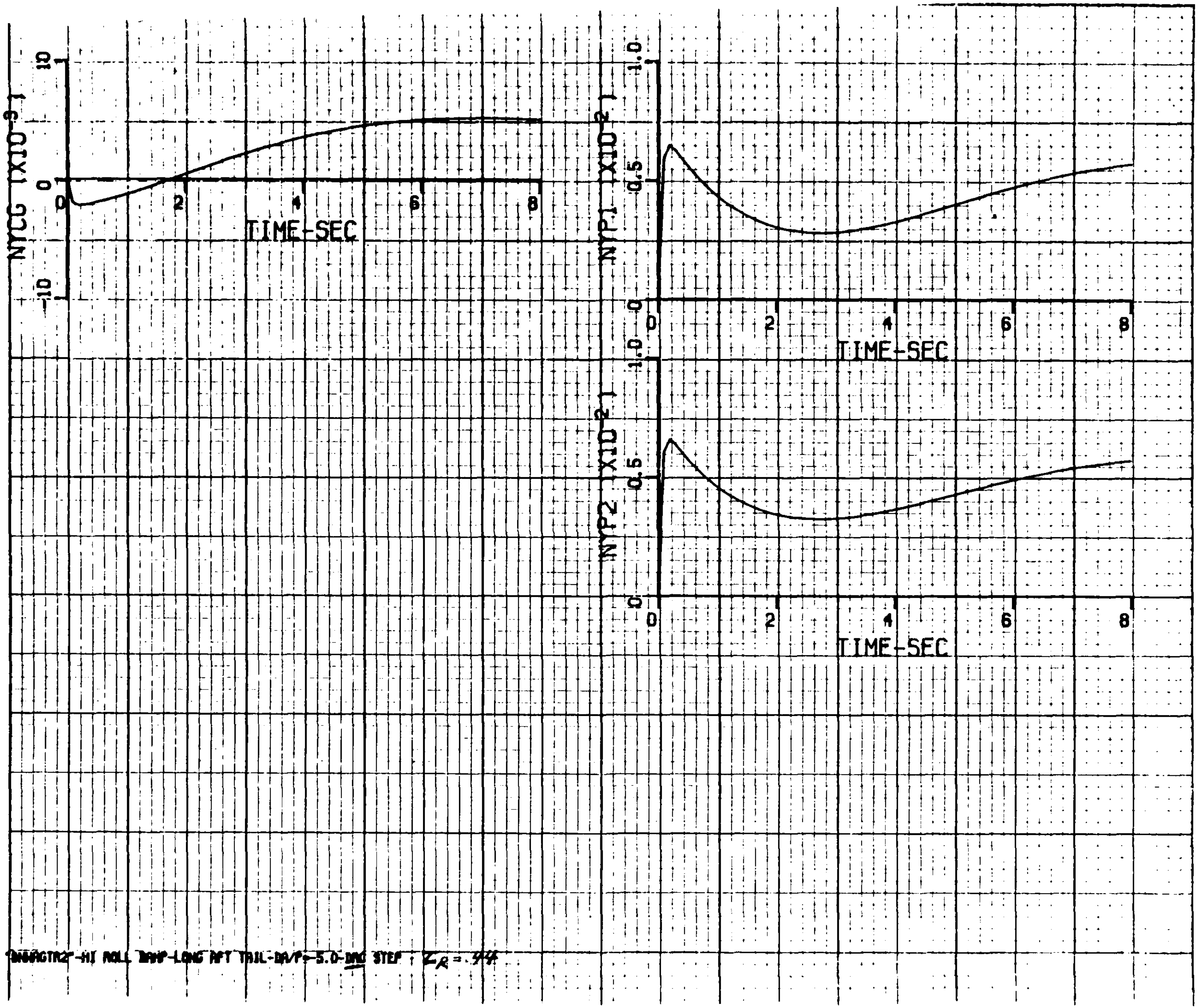

NYCG (X10-3)
NY50 (X10-2)
NYHI (X10-2)
NY70 (X10-2)
N11D (X10-2)
TIME-SEC
TIFS - LARGE A/C - LAT/DIR - ONE DEG
STEP



HI-ROLL DAMP-LONG AFT TAIL-DA/P=-5.0-DAC STEP - τ_A = .44


NYP1
NYP2
NYCG
TIME-SEC
TIME-SEC
TIME-SEC
0
2
4
6
8
0.40
0.20
-5.0
-10.0
0.0


BETA (X10-2)
R (X10-2)
P (X10-2)
PHI (X10-2)
R* (X10-3)
P* (X10-3)
TIME-SEC



NYCG (X10^-3)
10
0
-10
0
2
4
6
8
TIME-SEC
NYP1 (X10^-2)
1.0
0.5
0
TIME-SEC
NYP2 (X10^-2)
1.0
0.5
0
TIME-SEC
-HI ROLL DAMP-LONG AFT TAIL-DA/P=5.0-DEG STEP

Appendix III
PILOT COMMENT SUMMARIES

This appendix presents a brief summary of the important pilot comments for each evaluation. A transcription of the complete pilot comments is available from Calspan files. Along with the pilot comment summaries are the full description of the configuration, pilot ratings, flight number/configuration order on flight, date, meteorological conditions, and airport.

Configurations are presented in the following order:

Long Aft Tail, Canard, Short Aft Tail
α-Feedback, then q-Feedback
Low to High augmentation level
Time delay in the order $T_1 = A, B, C$

Lateral-directional configurations are presented last.
Thus, the comment summaries start with:

LONG AFT TAIL α AUGMENTATION — PILOT COMMENT SUMMARIES:

Unaug $T_1 = A, C$
Low α $T_1 = A, B, C$
Med α $T_1 = A, B, C$
High α $T_1 = A, B, C$
Ex-High α $T_1 = A$

High α, $n_z/\alpha = 3$ $T_1 = A$
High α, $n_z/\alpha = 2$ $T_1 = A$

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$		
Long	Unaug.	92.5	A	4.2	--	.87	18	A	PILOT	A
									RATING	6
									PIO	4 Apph. 1-2 Land.

FLT/CONF.	611/2	WIND	Headwind	VISIBILITY	Clear
DATE	7/29/80	TURB.	Moderate	AIRPORT	Buffalo

FEEL:

- Forces: In the approach the elevator forces felt a little heavy as I tended to chase pitch attitude. Had the beginnings of a PIO in pitch on the approach.
- Displacement: Displacements were correspondingly large.
- Sensitivity: Picked pretty good value.
- Trim: Don't remember ever using trim.

PITCH ATTITUDE RESPONSE:

- Initial: Slow and sluggish.
- Predictability: Tend to overshoot what I'm shooting for. So it's poor.
- Special Inputs: Put your inputs in slowly and wait.
- PIO Tendency: Tendency in approach but not in flare and touchdown.

AIRSPEED CONTROL: Poor in the approach, somewhat poor in VFR.

PERFORMANCE:

- Approach Tasks:
  ILS: Tended to have significant errors in attitude on the glide slope but they didn't integrate into significant errors in glide slope. I would get the attitude where I wanted it and look away and take care of something else and come back and the attitude was wrong.

  Visual (Sidestep): When I was visual and had continuous attitude information, it didn't seem that was a problem. Thrust lag makes it difficult to correct airspeed errors. Sidestep was taxing but adequately performed but airspeed gets out of hand while you're concentrating on sidestep.
- Landing Tasks: Flare and touchdown came out better than approach.
- Differences: Approach was worse than landing.

WIND AND TURBULENCE: Effects of turbulence were there.

SUMMARY COMMENTS: Most difficult task was the pitch control and airspeed control on instrument approach and during turns and in the sidestep. Only good feature was bank angle control. Had hell of a time trying to keep the pitch attitude where I wanted it in the approach, it kept sneaking off. Yet when I got visual, I didn't seem to have that problem. Pitch attitude control is poor and airspeed control is poor. The throttle response is terrible.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Long	Unaug.	92.4	C	4.2	--	.87	18	A	RATING 10
									PIO 4

FLT/CONF.	610/2	WIND	Headwind	VISIBILITY	Clear
DATE	7/29/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: The airplane is unstable in pitch. Very heavy in maneuvers. It is slow and sluggish and feels heavy in maneuvers. In steady state it wasn't heavy at all.
- Displacement: Large, very large any time I'm trying to make change in pitch attitude but in steady state I hardly see the displacement.
- Sensitivity: Initial response is very slow but sensitivity I picked was a good compromise.
- Trim: Trim was O.K..

PITCH ATTITUDE RESPONSE:

- Initial: Initial response was very slow and sluggish and the final response, it just keeps going. Difficult to pin down final response.
- Predictability:
- Special Inputs: Stay on top of it, continuous closed-loop control in pitch.
- PIO Tendency: Very definite PIO tendency. Tendency to oscillate even in normal maneuvering.

AIRSPEED CONTROL: Airspeed control very difficult partly because I had to spend so much time on attitude. Little warning that speed was departing from reference.

PERFORMANCE:

- Approach Tasks:
  - ILS: Performance not too bad even though I oscillated in pitch. Localizer fairly good. Airspeed performance was very poor, constantly making throttle corrections.
  - Visual (Sidestep): Visual difficult to fly flight path and airspeed.
- Landing Tasks: Very difficult to flare and touchdown, feel ground effect grab airplane and it was very difficult to counter. Very, very poor. Fighting a pushing shoving type battle all through the flare. You have very little precision of control of the touchdown point or sink rate and you're oscillating in pitch.
- Differences: Both approach and landing are difficult.

WIND AND TURBULENCE: Turbulence caused additional load on pilot.

SUMMARY COMMENTS: Major problem - pitch control and airspeed control. Control would be lost during some portion of required operation.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
									RATING	5
Long	α_{Lo}	92.5	A	4.2	--	.87	18	A	PIO	1
FLT/CONF.	611/1		WIND	Headwinds			VISIBILITY		Clear	
DATE	7/29/80		TURB.	Moderate			AIRPORT		Buffalo	

FEEL:

- Forces: Somewhat heavy like a big airplane.
- Displacement: Somewhat large.
- Sensitivity: What I picked was pretty good.
- Trim: Didn't use trim very much. It was O.K.. The trimmability of the airplane is poor. Perception of change in airspeed is poor.

PITCH ATTITUDE RESPONSE:

- Initial: Slow and sluggish.
- Predictability: Fair to poor. You tend to overdrive it and you have to stop it where it goes. If you don't pay attention you get a different attitude change than you want.
- Special Inputs:
- PIO Tendency: You tend to overshoot what you want but it's nowhere near a zero damped PIO.

AIRSPEED CONTROL: Poor control, perception of the change is poor. Touchdown airspeeds were pretty good.

PERFORMANCE:

- Approach Tasks:
  - ILS: Attitude tended to wander and I had to stay on it. It wasn't very stiff in attitude but the glide slope errors weren't too much of a problem. Airspeed was a problem.
  - Visual (Sidestep): Sidestep correction felt very heavy and ponderous but I could still do it within the time and distance available. About the limit however.
- Landing Tasks: Doesn't respond very quickly in flare and touchdown.
- Differences: Airspeed was the problem in the approach and attitude control was the problem in the transient and the flare and touchdown.

WIND AND TURBULENCE: Could handle the crosswind O.K..

SUMMARY COMMENTS: Major problem was the slow, sluggish pitch response.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT RATING PIO	
Long	α_{Lo}	92.5	B	4.2	--	.87	18	A	PILOT	A
									RATING	9
									PIO	

FLT/CONF.	609/3	WIND	SW @ 12 kt	VISIBILITY	Clear
DATE	7/25/80	TURB.	Light & Moderate	AIRPORT	Niagara

FEEL:
- Forces:
- Displacement:
- Sensitivity:

PITCH ATTITUDE RESPONSE:
- Initial:
- Predictability:
- Special Inputs:
- PIO Tendency:

AIRSPEED CONTROL:

PERFORMANCE:
- Approach Tasks:
  - ILS:
  - Visual (Sidestep):
- Landing Tasks:
- Differences:

WIND AND TURBULENCE:

SUMMARY COMMENTS:

Partial evaluation - last one on Flight 609. Didn't complete a landing because system dumped at 250 ft. Brief up and away evaluation and approach. Pilot did not follow comment card.

It was very slow responding in pitch and it had little or no or maybe negative speed stability. Although we were low on fuel, we tried an ILS approach. I sweated little green apples trying to fly this thing on the approach. The problem was airspeed control. Airspeed went from 140 to 160 and it didn't seem to correlate with anything I was doing. I was low on speed and normal pitch attitude with the power up at 70-80% and the airspeed not responding so I don't know whether this was the configuration or something was wrong.

Based on what I saw, the controllability is very much in question and that's just for doing the approach. It's a 9.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	α_{Lo}	92.5	C	4.2	--	.87	18	A	RATING	9 Land
									PIO	5 Up & Away 3

FLT/CONF.	608/3	WIND	SW @ 10 kt	VISIBILITY	Clear
DATE	7/25/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Seem heavy when making corrections.
- Displacement: Relatively large.
- Sensitivity:

PITCH ATTITUDE RESPONSE:

- Initial: Very delayed, very slow, ponderous airplane, Difficult to maneuver precisely.
- Predictability: Unpredictable.
- Special Inputs:
- PIO Tendency: Got PIO in flare and touchdown. No divergence.

AIRSPEED CONTROL: Not good, probably because of pitch control inaccuracy.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope not working. Localizer acquisition O.K.. But pitch problems interfered with localizer tracking.
  - Visual (Sidestep): Sidestep was small.
- Landing Tasks: Most degraded by pitch control. Flight path control degraded.
- Differences: Bad for both but worst thing was flare and touchdown.

WIND AND TURBULENCE:

SUMMARY COMMENTS: On basis of one landing I'll call it a 9 because I had a PIO going.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	B
Long	α_{Lo}	92.5	C	4.2	--	.87	18	A	RATING	7 Land 5 Appr
									PIO	4

FLT/CONF.	614/2	WIND	SW @ 8 kt	VISIBILITY	Clear
DATE	7/31/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Had high frequency feel system setup. Tended to chatter for big inputs, especially push force.
- Displacement:
- Sensitivity: O.K., except on occasion you ended up using large displacements. Not sure sensitivity changes would cure that problem.

PITCH ATTITUDE RESPONSE:

- Initial: Little on slow side.
- Predictability: Not really satisfactory. It was acceptable but there was some problem.
- Special Inputs: Keep inputs small.
- PIO Tendency: Mild tendency for low frequency PIO even on the approach.

AIRSPEED CONTROL: Really not very good on approach and poor in landing flare.

PERFORMANCE:

- Approach Tasks:
  - ILS: IFR was good, you can do the job as good as you want to concentrate.
  - Visual (Sidestep): Up to flare I thought it was under control.
- Landing Tasks:
- Differences:

I thought the flare and touchdown performance was poor, I don't know the exact reasons but I had problems down low close in. I thought everything was in order but they tell me the sink rate was high. I don't really have a feel for the sink rate at the altitude we are at (proper eye height for large airplane). You get a desire to get in there and do something right near the end and you end up either oscillating or hitting hard. The approach is clearly easier, the last 50 feet are tough in this one.

WIND AND TURBULENCE: Takes a while to get the nose around in crosswind correction.

SUMMARY COMMENTS: Major problem - lack of predictability in pitch. Inability to make correction right at end just before touchdown, makes it feel like the bottom drops out.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	α_{Med}	92.5	A	4.2	--	.87	18	A	RATING	6 Land 4 Up & Away
									PIO	3 Land ?

FLT/CONF.	609/2	WIND	SW @ 12 kt	VISIBILITY	Clear
DATE	7/25/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Forces in steady turn light. Trim only fair because of shallow force change with 8-10 kt speed.
- Displacement: Heavy in elevator and ailerons.
- Sensitivity:

PITCH ATTITUDE RESPONSE:

- Initial: Sluggish initially delayed. It doesn't want to move but if you get it on the glide slope, it will kind of stay there.
- Predictability: Predictability not too bad but it's difficult because of long response time. Predictability is poor if you want to make a response change in a hurry.
- Special Inputs: You overdrive it.
- PIO Tendency: No

AIRSPEED CONTROL:

PERFORMANCE:

- Approach Tasks: Good
  ILS:

  Visual (Sidestep): Relatively easy even with an apparent wind shear.
- Landing Tasks: Tended to balloon. Too inert, too difficult to move it and then if you get it going, it's very difficult to correct it in time to control flight path.
- Differences: Landing is relatively difficult. Can't make corrections close in or counter turbulence.

WIND AND TURBULENCE: Contributed to balloon tendency, also ground effect. Didn't notice significant difference between canned turbulence and real turbulence, tried both.

SUMMARY COMMENTS: Turn coordination is excellent but if you have to do any directional trimming, it's very difficult. Have to put in a trim correction and wait 4-5 sec to see what happened. Approaches were interrupted by system dumps in initial flights. Traced to electrical transient that cause the digital computer to halt when safety pilot armed a hydraulic pump on each approach.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	α_{Med}	92.5	B	4.2	--	.87	18	A	RATING	7 Land 4 Up & Away
									PIO	3
FLT/CONF.	608/2		WIND	SW @ 10 kt			VISIBILITY		Clear	
DATE	7/25/80		TURB.	Light to moderate			AIRPORT		Niagara	

FEEL:

- Forces: Little heavy in maneuvers. Some stick force when off speed. The airplane seemed sticky in pitch. It didn't seem to want to go where I wanted it to go. To get a change required a lot of force.
- Displacement: Reasonable displacements.
- Sensitivity:

PITCH ATTITUDE RESPONSE:

- Initial: I didn't have good control of attitude.
- Predictability: Didn't have as much precision in pitch as I would like. Pitch attitude control required a lot of effort on my part and was objectionable.
- Special Inputs:
- PIO Tendency: No.

AIRSPEED CONTROL: Fair.

PERFORMANCE:

- Approach Tasks: ILS: Attention to attitude caused deterioration in localizer tracking.

  Visual (Sidestep): No particular difficulty.
- Landing Tasks: Uncomfortable in flare. Didn't get to complete 2nd landing, safety pilot took control. I was at 138 kts and had not touched down yet.
- Differences: The worst area is flare and touchdown.

WIND AND TURBULENCE:

SUMMARY COMMENTS: Can't make the airplane do what I want in pitch. It's flying itself. I can't consistently get it to do what I want. The pitch control is the primary reason for the rating.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	B
Long	α_{Med}	92.5	B	4.2	--	.87	18	A	RATING PIO	5 Land 2 Appr. 2

FLT/CONF.	614/1	WIND	SW @ 8 kt	VISIBILITY	Clear
DATE	7/31/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Nothing of note in terms of forces and displacements.
- Displacements:
- Sensitivity: No complaint.

PITCH ATTITUDE RESPONSE:

- Initial: Reasonable initial response, except right near the end, I seemed to lose track of sink rate.
- Predictability:
- Special Inputs: No special.
- PIO Tendency: No PIO.

AIRSPEED CONTROL: Reasonable except right near the end when I tried to stretch it out to get sink rate under control.

PERFORMANCE:

- Approach Tasks:
  - ILS: Can do the job.
  - Visual (Sidestep): It's only right near the end that you have a problem.
- Landing Tasks: The flare and touchdown performance was not really satisfactory. Don't like the last part - had feeling bottom was falling out.
- Differences:

WIND AND TURBULENCE: No problem with crosswind. I tried to pay more attention to lineup but I'm still not doing it totally the way I would in a real airplane. I got to work more on that.

SUMMARY COMMENTS: I could notice it takes a long time to get the nose around with the rudder during crosswind correction Major problem was the last pa t of the flare. It's marginally stable, a little tendency to oscillate but you can keep it under control. Funny feeling when I get really close to the ground, I can't establish an attitude and as a result went long and happened to hit with a reasonable sink rate but you worry that you are going to plow into the ground.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Long	α_{Med}	92.5	C	4.2	--	.87	18	A	RATING 8 PIO 4

FLT/CONF.	610/3	WIND	Headwind	VISIBILITY	Clear
DATE	7/29/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: On heavy side especially for transient maneuvering.
- Displacement: Little on large side but not a serious objection.
- Sensitivity: Feels low. Compromise between preventing a PIO and yet having adequate control of pitch.
- Trim: Didn't have occasion to use trim.

PITCH ATTITUDE RESPONSE:

- Initial: Sluggish.
- Predictability: Poor,requires continuous closed-loop control to generate attitude changes.
- Special Inputs: Continuous pitch attitude control. Overdrive to get it going and stop it where you want.
- PIO Tendency: Definite PIO tendency in turbulence. Less tendency in flare during smooth air.

AIRSPEED CONTROL: Poor airspeed control.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope and localizer performance was excellent. Airspeed fair and throttle response objectionable.
  - Visual (Sidestep): Felt heavy in roll during sidestep.
- Landing tasks: Sluggish initially and tendency to overdo the pitch attitude. Tendency to overshoot in pitch and oscillate during flare and touchdown. Difficulty with precision control of the flight path close in. Sink rate was not very controllable. Accepted anything that was not outside limits, just didn't have any precise control of the touchdown conditions.
- Differences: Visual and landing was more difficult than IFR approach.

WIND AND TURBULENCE: Turbulence definitely degraded this configuration particularly in flare and touchdown.

SUMMARY COMMENTS: Major problems - pitch control, flight path control and airspeed control.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	α_{Hi}	92.5	A	4.2	--	.87	18	A	RATING	6 Land 4 Up & Away
									PIO	3

FLT/CONF.	607/1	WIND	Headwind	VISIBILITY	Clear
DATE	7/24/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: Reasonable.
- Displacement: Large.
- Sensitivity:

PITCH ATTITUDE RESPONSE:

- Initial: Slow, ponderous but not seriously objectionable until got to flare and touchdown.
- Predictability:
- Special Inputs: Attention and effort to eliminate or prevent motion in pitch.
- PIO Tendency: No PIO but undesirable motions occur in pitch in flare.

AIRSPEED CONTROL:

PERFORMANCE:

- Approach Tasks:
  - ILS: Localizer good, ILS good.
  - Visual (Sidestep): Relatively easy to correct.
- Landing Tasks: Pitch response was a little slow and sluggish in flare with tendency to overrotate.
- Differences:

WIND AND TURBULENCE:

SUMMARY COMMENTS: Practice evaluation flight. Encountered a number of system problems. Pilot not sure the evaluation was valid.

Pitch flare maneuver was most difficult. Tendency to overrotate in pitch in the flare and touchdown was primary reason for the rating. Good turn coordination but feel lateral acceleration in abrupt rolls that is not related to sideslip.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT RATING	A
Long	α_{Hi}	92.5	A	4.2	--	.87	18	A		5 Land 3 Up & Away
									PIO	--

FLT/CONF.	608/1	WIND	SW @ 10 kt	VISIBILITY	Clear
DATE	7/25/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Pitch breakout forces are objectionably high and may be heavier on a push than for a pull.
- Displacement: Has some stick force stability with speed. Displacements relatively large forces heavy in turn.
- Sensitivity:

PITCH ATTITUDE RESPONSE:

- Initial: Pitch attitude control is good as long as you do it slowly.
- Predictability:
- Special Inputs:
- PIO Tendency:

AIRSPEED CONTROL: Fairly good in up and away flight, shallow gradient of force with speed so perception of being off speed is low and compounded by breakout forces. Airspeed control on the approach in turbulence was poor.

PERFORMANCE:

- Approach Tasks:
  ILS:

  Visual (Sidestep): Some tendency to drift in making lineup, interfered with flare task.
- Landing Tasks: Pitch control in flare was ponderous. Felt behind airplane. Overrotated a little in corrections.
- Differences:

WIND AND TURBULENCE:

SUMMARY COMMENTS: It's a big ponderous airplane. Turn coordination is very good. Thrust response is quite objectionable, it takes way too long to reach steady state. Airspeed control in turbulence is a problem.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Long	α_{Hi}	92.5	A	4.2	--	.87	18	A	RATING 2
									PIO 1

FLT/CONF.	613/5	WIND	Headwind	VISIBILITY	Clear
DATE	7/30/80	TURB.	Light	AIRPORT	Niagara

FEEL:
- Forces: O.K..
- Displacement: O.K..
- Sensitivity: Satisfactory.
- Trim: Trim satisfactory.

PITCH ATTITUDE RESPON
- Initial: By my standards, little bit sluggish but for a big airplane I think it was good.
- Predictability: It's predictable, pleased with last approach. Near the end I tended to panic, I wanted to do something near the end and I was able to smoothly control it.
- Special Inputs:
- PIO Tendency: No PIO.

AIRSPEED CONTROL: Kind of a pain in the butt, I think it's because of the turbulence but the throttle response is so slow you can't do anything about it right away. So you are bothered by it. Tended to fly few knots fast.

PERFORMANCE:
- Approach Tasks:
  - ILS: Good as you want to make it.
  - Visual (Sidestep): No problem with sidestep. I have a tendency to say "Oh, what the hell, I'm not really going to touchdown so I don't have to be quite straight." I'll have to try to pay a little more attention to that in the future.
- Landing Tasks: No problem with flare and touchdown. Can fly this airplane fairly naturally, just back off a little bit not trying to fly aggressively.
- Differences: Nothing significant between approach and landing.

WIND AND TURBULENCE: Turbulence namely noticed in airspeed and a tendency to wallow a little bit. It's not like a smaller airplane bouncing around.

SUMMARY COMMENTS: Aileron feel system tends to oscillate when I put in reasonable size input. It is predictable in pitch.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT A
Long	α_{Hi}	92.5	A	4.2	--	.87	18	A	RATING 6
									PIO 3

FLT/CONF.	618/3	WIND	5-10 kt tailwind	VISIBILITY	Clear
DATE	8/4/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Steady elevator is required in a steady turn. The forces felt moderate.
- Displacement: Moderate too.
- Sensitivity: About right.
- Trim: Didn't trim.

PITCH ATTITUDE RESPONSE:

- Initial: Seems to be there, not quick but not delayed like some I've seen.
- Predictability: Fair.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Some trouble with airspeed control.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope - don't remember, don't think it was too bad. Busy on glide slope and localizer.
  - Visual (Sidestep): Sidestep OK.
- Landing Tasks: Flare and touchdown - I just seemed to have problems between what I feel and what is coming out, I don't even know if I'm using a special technique.
- Differences: Flare and touchdown more difficult.

WIND AND TURBULENCE: Turbulence is troublesome. I guess I feel like I'm on the end of a big whip, maybe that's what I'm talking about, I don't know.

SUMMARY COMMENTS: The major problem was probably airspeed control and also the final flight path control in flare and touchdown. I'm not very confident with this configuration. My speed doesn't seem to be well connected to my airplane and the flight path doesn't seem to be well connected to what I am doing in pitch. It seemed peculiar to me.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Long	α_{Hi}	42.5	B	4.2	--	.87	18	A	RATING 7
									PIO 4

FLT/CONF.	610/1	WIND	Headwind	VISIBILITY	Clear
DATE	7/29/80	TURB.	Moderate	AIRPORT	Niagara

FEEL: NOTE: The pilot flew this evaluation approximately 10 kts below the reference speed. We don't know why.

- Forces: Elevator was very heavy in turns even after increasing the gain by 50%.
- Displacement: Displacements somewhat large. The roll forces were heavy during maneuvers.
- Sensitivity: Sensitivity is low both in dynamic sense, nose is delayed in maneuvers, and also heavy forces in steady turn.

PITCH ATTITUDE RESPONSE:
- Initial: Slow sluggish.
- Predictability: Not too bad but it's not good.
- Special Inputs: Crank your gain down and drive it slowly.
- PIO Tendency: Tendency when trying to maneuver fast.

AIRSPEED CONTROL: Poor, kept getting slow, don't know why.

PERFORMANCE:
- Approach Tasks:
  - ILS: ILS and localizer not too bad. Problem was with airspeed control. Didn't seem good at all. The throttles were surging and that tended to degrade the quality of the simulation but I don't think it was a major factor.
  - Visual (Sidestep): Visual approaches were difficult because of airspeed control and heavy elevator forces. Sideslip maneuver was extremely difficult because of sluggish heavy feeling roll response.
- Landing Tasks: Flare and touchdown was difficult, and high workload. Airspeed control poor. Ground effect noticeable.
- Differences: Approach and landing both difficult. Lineup correction is good evaluation maneuver. Airspeed control was problem. Pitch control in flare a problem.

WIND AND TURBULENCE: Turbulence aggravated things. Crosswind not much of a problem. Lateral-directional characteristics a factor in evaluation.

SUMMARY COMMENTS: Major problems - roll-flight path lineup. Airspeed control, heavy elevator forces in turn, sluggish pitch response.

Pilot flew at lower speed and higher angle of attack than planned reference values. This caused heavy control forces and more severe backside of power curve characteristics.

These problems diminished during a calibration record after the evaluation. Presumably this record was taken at the correct airspeed.

The system was dumped by the safety pilot in one landing attempt because the flaps were near the trailing edge up limit. This was a result of low airspeed.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT A RATING 6 PIO 3
Long	α_{Hi}	92.5	B	4.2	--	.87	18	A	

FLT/CONF.	626/4	WIND	5-10 kt tailwind	VISIBILITY	Overcast but app's in clear air.
DATE	8/11/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Kind of heavy on first approach. Increased command gain for second approach, forces felt lighter - medium.
- Displacement: Significant, at least medium.
- Sensitivity: Like the higher command gain better. Didn't really have to trim.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response delayed.
- Predictability: Somewhat poor because you had to wait, but something happens and it comes on enough that I don't have a strong PIO tendency.
- Special Inputs: Tend to overdrive it to get it started.
- PIO Tendency: There is a hint of a PIO tendency.

AIRSPEED CONTROL: Fair.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope and localizer not bad. Airspeed only fair as usual.
  - Visual (Sidestep): Able to make lineup well. Little trouble with the pitch approach path.
- Landing Tasks: Didn't have good positive control of flare and touchdown by any sense. Have to stay on top of it.
- Differences: Visual part more difficult. Not a whole lot more but noticeable.

WIND AND TURBULENCE: No comment.

SUMMARY COMMENTS: The pitch control in the flare and touchdown is adequate but it's certainly not desirable. The good feature is the lateral-directional. Would really have liked a third approach, uncertain about what to rate it, whether it's a 5 or a 6.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Long	α_{Hi}	92.5	C	4.2	--	.87	18	A	RATING 6 Land 4.5 Up & Away PIO 3 Land 2 Up & Away

FLT/CONF.	609/1	WIND	SW @ 12 kt	VISIBILITY	Clear
DATE	7/25/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Breakout forces are a little objectionable. Elevator force in turn is noticeable.
- Displacement:
- Sensitivity:

PITCH ATTITUDE RESPONSE:

- Initial: There is a big delay. Sluggish in pitch, inert. Requires too much attention.
- Predictability: Poor. Goes too far. Look away and come back it's not in same place.
- Special Inputs: Put in little extra to get it going.
- PIO Tendency: Not very much.

AIRSPEED CONTROL: Thrust response has a big delay. Speed control is adequate.

PERFORMANCE:

- Approach Tasks:
  - ILS: Fairly good but it was very high workload, required continuous attention.
  - Visual (Sidestep): Sidestep went well, not very comfortable airplane.
- Landing Tasks: Touchdown was a problem, I was kind of nudging it to where it had to go.
- Differences: Same problems but landing is more critical.

WIND AND TURBULENCE: Turbulence not bothersome. Crosswind not overly difficult.

SUMMARY COMMENTS: Turn coordination is excellent.
Major problem is the initial response sluggishness and difficulty of predicting where the final response is going in pitch.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B RATING 7 Land, 5 Appr PIO 3
Long	α_{Hi}	92.5	C	4.2	--	.87	18	A	

FLT/CONF.	614/3	WIND	SW @ 8 kt	VISIBILITY	Clear
DATE	7/31/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: We changed the feel system setup because there was chatter in the feel on occasion. (Reduced frequency). Final setting was OK.
- Displacement:
- Sensitivity: Hard to figure out exactly what was going on. Airplane seemed hard to trim. I was using trim a lot. I don't have any real complaints about sensitivity. I used trim a lot and could not get the airplane trimmed to my satisfaction.

PITCH ATTITUDE RESPONSE:

- Initial:
- Predictability:
- Special Inputs:

Pitch response - it wasn't oscillatory but it wandered around and it was not predictable in that sense. When I concentrated on putting an input in, I could get it to stop where I wanted to.

- PIO Tendency: No PIO tendency.

AIRSPEED CONTROL: Poor and I don't understand why. Tended to be fast with power settings that I thought were right. Airspeed control was not good.

PERFORMANCE:

- Approach Tasks:
  - ILS: OK on ILS.
  - Visual (Sidestep): Tended to be turning in too close to airport. Got crosswind information a little late.
- Landing Tasks: Flare and touchdown - that's where I had problems and I am really having problem trying to figure out why it's happening. Had everything lined up and the bottom drops out. Not able to get touchdown performance I desire.
- Differences: Landing clearly more difficult than approach.

WIND AND TURBULENCE: Not a big factor.

SUMMARY COMMENTS: Noticed low frequency Dutch roll. Have to anticipate crosswind correction.
Major problem was a little wandering in pitch. Lack of precision, but mostly the last part of landing. Feels like the bottom is dropping out under 20 feet or so.

TAIL	AUG.	X_p	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	α_{Hi}^{Ex-}	92.5 C.R.	A	4.2	--	.87	18	A	RATING	6 appr 5 land
									PIO	2

FLT/CONF.	629/4	WIND	260° @ 15 kt	VISIBILITY	Partly cloudy
DATE	8/12/80	TURB.	Moderate	AIRPORT	Buffalo

FEEL:

- Forces: Medium
- Displacement: Medium to a little on large side during approach but in the flare and touchdown, the displacements were quite a bit smaller and forces not any heavier than medium.
- Sensitivity: I lightened it from where we started. Pretty good selection. I'll ignore trim question.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response was definitely there, I could feel it in the seat of my pants.
- Predictability: Predictability of final response in the flare and touchdown was pretty good, well it wasn't good but was pretty fair. On the approach though it felt kind of ponderous or more difficult to predict.
- Special inputs: I don't know. I probably overdrove it a little in pitch in the approach.
- PIO Tendency: Not really any PIO tendency.

AIRSPEED CONTROL: Fair.

PERFORMANCE:

- Approach Tasks:
  - ILS: Fair to good glide slope, good localizer.
  - Visual (Sidestep): Roll control was easy in sidestep. A little uncertain in pitch but no real problem.
- Landing Tasks: It seemed to change character in the flare and touchdown. I was able to control sink rate with the elevator. I didn't do flare properly but I could feel prompt response to my elevator inputs and it helped me to keep from putting in too much elevator.
- Differences: Didn't like the airplane on the approach. I could get performance with it but it required a lot of workload. It got a whole lot better in flare and touchdown.

WIND AND TURBULENCE:

SUMMARY COMMENTS: On approach it felt ponderous in pitch. Didn't seem to hold attitude. Not a very comfortable airplane. When I use the elevator, I get a very positive, early indication that I have done something but I had to wait a while to see what it is going to be. Flight path control on approach was my problem. I had trouble getting on the glide slope and making corrections. Once on, it was pretty easy to fly.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Long	α_{Hi}	92.5	A	3	--	.87	18	A	RATING 4-1/2
									PIO 1

FLT/CONF.	614/4	WIND	SW @ 8 kt	VISIBILITY	Clear
DATE	7/31/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Have to hold back pressure in turn, really noticed that if I didn't do it, then the airspeed got out of hand.
- Displacement: Felt a lot of trimming required in turn and then when you level off, you tend to lose track of trim. Occasionally you notice heavy forces in turns.
- Sensitivity: Sensitivity is O.K.. Had to use trim a lot and sometimes not too successfully, especially if you don't have it organized when you went into flare.

PITCH ATTITUDE RESPONSE:

- Initial: Pitch response itself - nothing really stands out.
- Predictability: Moderate to satisfactory.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Once I learned to work at it, it got better and I think you can adjust to its characteristics and achieve airspeed control.

PERFORMANCE:

- Approach Tasks:
  - ILS: Can do good job on ILS. Just a question of concentration.
  - Visual (Sidestep): Had some problems which may be related to getting the trim organized.
- Landing Tasks: Had problems on several approaches but think performance can be attained. Keep it in trim.
- Differences: Landing slightly more difficult than approach.

WIND AND TURBULENCE:

SUMMARY COMMENTS: "Wandering" of trim was major problem. Airspeed control difficulty.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
									RATING 6
Long	α_{Hi}	92.5	A	3	--	.87	18	A	PIO 3

FLT/CONF. 618/1	WIND	5-10 kt tail wind	VISIBILITY	Clear
DATE 8/4/80	TURB.	NIL	AIRPORT	Niagara

FEEL:

- Forces: Heavy.
- Displacement: Moderate.
- Sensitivity: Little on heavy side, it was mostly bothersome in the turn. I should have picked a little higher sensitivity.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed, slow.
- Predictability: Poor, affects you both on the ILS and glideslope and on flare and touchdown.
- Special Inputs: You probably overdrive it but you have to watch that you don't overdrive it too much because then you overshoot the final response.
- PIO Tendency: There is a tendency, not so much oscillation as it is a tendency not to have full control over the flight path.

AIRSPEED CONTROL: Airspeed control was somewhat difficult probably because the attitude was difficult to peg where I wanted it when I wanted it.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glideslope performance fairly good but high workload. Localizer was moderately high workload. Airspeed required attention.
  - Visual (Sidestep): Sidestep relatively easy.
- Landing Tasks: Flare and touchdown, the problems seem to be that it is just a ponderous airplane to try to flare. If you are set up and only put in small inputs, it goes well. If you get off, it takes a lot of space to correct it back in pitch and then the airspeed tends to bleed off too much.
- Differences: Flare and touchdown most critical, but the approach was also objectionable.

WIND AND TURBULENCE: Turbulence was there and served as a disturbance but it was not unduly objectionable ridewise.

SUMMARY COMMENTS: Major problem was the sluggish pitch response.
Good features - lateral directional.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Long	α_{Hi}	92.5	A	2.0	--	.87	18	A	RATING 5-1/2
									PIO 1

FLT/CONF.	615/1	WIND	Headwind	VISIBILITY	Clear
DATE	7/31/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces and Displacements: Required a fair amount of aft stick in the turn. I had to trim a fair amount to try and get the forces organized. Airplane tended to hold the attitude once you trimmed it in the turn. I came around final turn and pushed the nose down and then relaxed the force and the nose came back up. You had to trim quite a lot.
- Sensitivity: In retrospect, could have used a little higher sensitivity but I wouldn't think a significant amount.

PITCH ATTITUDE RESPONSE:

- Initial: Pitch attitude response I thought was reasonable.
- Predictability: It was predictable.
- Special Inputs: No special inputs.
- PIO Tendency: No tendency to PIO.

AIRSPEED CONTROL: Airspeed left a little to be desired for some reason. Had a little problem with airspeed control. It seemed to change on a couple of occasions for reasons that I couldn't find. I might comment on the throttles. I use them in incremental fashion, they are not integrated with the rest of what I do because I make an input and then I have to wait to see what happens.

PERFORMANCE:

- Approach Tasks:
  - ILS: ILS performance was satisfactory.
  - Visual (Sidestep): Visual lineup was O.K.. Sometimes not allowing enough time to get stabilized with respect to crosswinds. That's not the fault of the airplane but the fault of the initial conditions.
- Landing Tasks: I felt comfortable in flare until the very last and then I seemed to allow the sink rate always to get a little higher and try to grab it at the end.
- Differences: Not a significant difference except at end of flare and touchdown. Getting a stabilized sink rate at the end was not easy for me. I seemed to pull back and think I was getting an attitude change and apparently wasn't. (Because sink rate did not respond as expected for the attitude?)

SUMMARY COMMENTS: Major problem - stabilizing the airplane under 50 ft.. It wasn't a question of an oscillation, it was I just couldn't seem to get conditions set correctly.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT A
Long	α_{Hi}	92.5	A	2.0	--	.87	18	A	RATING 7
									PIO 4

FLT/CONF.	618/2	WIND	5-10 kt tail wind	VISIBILITY	Clear
DATE	8/4/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Lightened the forces by increasing command gain. Turning final the elevator forces got very, very heavy, angle of attack went up around 8° but I added power and it just kept coming around and when I leveled the wings, it got a whole lot lighter and gradually back to trim and like the configuration I had flown on ILS. I don't understand what's going on.
- Displacement: Medium.
- Sensitivity: Increased gain. Wouldn't want it any lighter.

PITCH ATTITUDE RESPONSE:

- Initial: It's hard to describe. In flare initial response is modestly quick, it's not delayed like some.
- Predictability: Visually the predictability is not too bad, however, on the ILS, the initial response felt delayed and predictability of final response is poor. It behaves nonconsistently in turn. Large forces and large increases in angle of attack as bank is increased to tighten the turn.
- Special Inputs:
- PIO Tendency: I had a PIO tendency.

AIRSPEED CONTROL: Not particularly good, required attention.

PERFORMANCE:

- Approach Tasks: Tended to oscillate in pitch, required a lot of attention.
  ILS: Localizer was pretty good. Airspeed was degraded, didn't like it IFR.

  Visual (Sidestep): Sidestep easy.
- Landing Tasks: Flare and touchdown were reasonably controllable. No special control technique. Could correct errors.
- Differences: The approach was worse, tendency to pitch oscillate and large attention required for ILS.

WIND AND TURBULENCE: Crosswind not a problem. Turbulence noticeable.

SUMMARY COMMENTS: Major problem: pitch attitude control in the IFR. Tendency to oscillate in pitch. Also, heavy forces that were required in steeper bank turns. I had difficulty in just flying the turning part of the approach.
Good features: lateral-directional and the flare and touchdown weren't bad. It was a lot easier to land than some I have rated a 6. It was also more comfortable in some regards on the ILS than some but overall it's a 7.

LONG AFT TAIL q AUGMENTATION — PILOT COMMENT SUMMARIES

Low q — $T_1 = A, C$

Med q — $T_1 = A, B, C$

High q $(X_{PCR} = 92.5')$ — $T_1 = A, B, C$

High q $(X_{PCP} = 32.5')$ — $T_1 = A$

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Long	q_{Lo}	92.5	A	4.2	1.0	.87	18	A	RATING 10
									PIO 5

FLT/CONF.	617/2	WIND	variable	VISIBILITY	very low, < 1 mi
DATE	8/1/80	TURB.	Very turbulent. Thunder storms and lightning.	AIRPORT	Niagara

Abandoned evaluation, no landings.

FEEL:

- Forces: Quite heavy.
- Displacement: Large.
- Sensitivity: Heavy as could stand because to increase the gain would aggravate PIO tendency.
- Trim: Didn't use trim.

PITCH ATTITUDE RESPONSE:

- Initial: There isn't any initial response.
- Predictability: Overcontrol and overshoot.
- Special Inputs: Make input, take it out and wait to see what you get.
- PIO Tendency: Tend to get pitch oscillations as much as $\pm 5^{o}$ pitch even flying straight and level. Very strong tendency to PIO.

AIRSPEED CONTROL: Extremely difficult. Had to carry higher thrust to hold speed during pitch oscillations.

PERFORMANCE:

- Approach Tasks:
  - ILS: Tended to get errors in glide slope and localizer. Difficult to correct. Have to nudge it around. Airspeed varied 140-160 kt. in approach.
  - Visual (Sidestep): Broke out slow, started sidestep correction and lost speed, got down to 132 kt and safety pilot took control. Had no cues airspeed was off. No stick force cues.
- Landing Tasks: Didn't get to do landing.
- Differences:

WIND AND TURBULENCE: It wasn't really too bad in turbulence. Main problem in turbulence was large airspeed excursions due to sluggish throttle response and difficulty correcting attitude. The ride was not causing the difficulty.

SUMMARY COMMENTS: Major problem - Pitch PIO and lack of airspeed cues.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	q_{Lo}	92.5	A	4.2	1.0	.87	18	A	RATING	8
									PIO	4

FLT/CONF.	626/3	WIND	5-10 kt tailwind	VISIBILITY	overcast but app's in clear air
DATE	8/11/80	TURB.	Light	AIRPORT	Niagara

FEEL:
- Forces: Heavy until I increased the control gain, then medium.
- Displacement: Large.
- Sensitivity: Low, but wouldn't want it any more sensitive.
- Trim: Didn't use trim.

PITCH ATTITUDE RESPONSE:
- Initial: Extremely delayed.
- Predictability: Very poor.
- Special Inputs: Use open loop pulse input and wait to see what response you get. In flare you're flying it with pulses like it is an acceleration control system.
- PIO Tendency: Very, very strong. Low frequency galloping pitch oscillation.

AIRSPEED CONTROL: Surprisingly the airspeed control was pretty good. Fair to poor but I thought it was going to really get out of hand, yet it came out acceptably well.

PERFORMANCE:
- Approach Tasks:
  - ILS: Not so good and required very high workload because of the attention.
  - Visual (Sidestep): Sidestep easy to correct but lost pitch flight path and started PIO.
- Landing Tasks: Very gross PIO but was able to land. Wouldn't want to make very many landings.
- Differences: Visual approach and touchdown most difficult but problems on approach too.

WIND AND TURBULENCE: Effects not real strong but you could never really get it set up. Pitch constantly required attention. Lat-Dir characteristics were good.

SUMMARY COMMENTS:

Major problem is the pitch control, delayed pitch response, tendency to PIO in flare and touchdown. If I try to use proportional control, I invariably overshoot the attitude by a factor of 2. You either relax and nudge it around or you use a dither technique, i.e. a high gain loop closure with pulses in the pitch control.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT	A
Long	q_{Lo}	92.5	C	4.2	1.0	.87	18	A	RATING	10
									PIO	5

FLT/CONF.	611/4	WIND	Headwind	VISIBILITY	Clear
DATE	7/29/80	TURB.	Moderate	AIRPORT	Buffalo & Niagara

FEEL:

- Forces: Very heavy
- Displacement: Large
- Sensitivity: Couldn't have stood it any higher because of PIO.

PITCH ATTITUDE RESPONSE:

- Initial: Very, very delayed.
- Predictability: Almost totally unpredictable - IFR anyway.
- Special Inputs: Generate tremendous lead and stay out of loop as much as possible.
- PIO Tendency: Very strong PIO tendency. Very difficult to avoid. Very difficult to damp.

AIRSPEED CONTROL: Substantial errors because of inadequate control of attitude.

PERFORMANCE:

- Approach Tasks:
  - *ILS*: Glideslope was absolutely terrible. Safety pilots commented on how bad it was, almost took control twice. Localizer wasn't too bad, matter of attention available.
  - Visual (Sidestep): Didn't do sidestep. No crosswind.
- Landing Tasks: Flare and touchdown was real good on the one landing. PIO damped out and I let it land.
- Differences: Approach was much worse than visual part. Turbulence excites PIO tendency.

WIND AND TURBULENCE: Lat-Dir. Thank goodness they were all right.

SUMMARY COMMENTS: Major problem - IFR PIO in pitch.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Long	q_{Lo}	92.5	C	4.2	1.0	.87	18	A	RATING 9
									PIO 5

FLT/CONF.	613/2	WIND	Headwind	VISIBILITY	Clear
DATE	7/30/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Very heavy. High frequency feel system was set up. Tended to chatter for large forces, especially push force. Very distracting to pilot on this evaluation.
- Displacement: Very big.
- Sensitivity: Increased by factor of 2, didn't seem to make any difference to my capabilities.

PITCH ATTITUDE RESPONSE: Attitude response was terrible.

- Initial: Very poor initial.
- Predictability: Almost nonexistent. I was really out of phase with it.
- Special Inputs: I tried being a little smoother and I tried being abrupt. I would get it calmed down and try to fly with trim but still felt I was in an incipient PIO all the time.
- PIO Tendency:

AIRSPEED CONTROL: Poor as a result of poor attitude control.

PERFORMANCE:

- Approach Tasks:
  - ILS: Poor. More difficult than visual.
  - Visual (Sidestep): Better than IFR but not very happy about it.
- Landing Tasks: Didn't get to do landing because of system dumps.
- Differences: Approach was bad, I could keep errors smaller when visual.

WIND AND TURBULENCE: Crosswind was not a problem. Turbulence caused it to wallow around but I didn't have to do anything.

SUMMARY COMMENTS: Major problem was PIO in pitch.
Pilot complained about the turbulence effect rating scale.
Too many words to read.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT A
Long	q_{Med}	92.5	A	4.2	1.0	.87	18	A	RATING 4.5
									PIO 3

FLT/CONF.	612/3	WIND	12 kt headwind	VISIBILITY	Clear
DATE	7/30/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- *Forces:* Medium. The forces even feel light because I don't have to do anything in the steady turn. They are very comfortable. I wouldn't want them any lighter.
- Displacement: Medium.
- Sensitivity: About right.
- Trim: Didn't use trim.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed.
- Predictability: Not bad.
- Special Inputs: Don't think so.
- PIO Tendency: No PIO.

AIRSPEED CONTROL: *Requires attention but not significant factor.*

PERFORMANCE:

- Approach Tasks: Good.
  - ILS: Thrust response is delayed and bothersome but tolerable.
  - Visual (Sidestep): Lineup correction was easy. Crosswind correction easy.
- Landing Tasks: The flare and touchdown is difficult. OK if everything set up just right. If you are off as I was once, I found it difficult to correct. Sluggish initial response but you have reasonable control of final response so it's not really bad. You don't want to try and correct a big error, you do better to go around.
- Differences: Landing is primary difficulty and it's the slow pitch response.

WIND AND TURBULENCE: Turbulence and wind not a particular factor. Lat-Dir characteristics basically good.

SUMMARY COMMENTS: Major problem - Correction of large errors close to ground and tendency to overshoot correction.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	q_{Med}	92.5	B	4.2	1.0	.87	18	A	RATING	5
									PIO	3

FLT/CONF.	612/1	WIND	12 kt headwind	VISIBILITY	Clear
DATE	7/30/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Pleasant.
- Displacement: Moderate when you force yourself to do things slowly.
- Sensitivity: Pleasant.
- Trim: Didn't have to trim.

PITCH ATTITUDE RESPONSE:

- Initial: Appears delayed.
- Predictability: Degraded. Tend to overcontrol.
- Special Inputs: Force yourself to slow down, relax, do every thing slowly.
- PIO Tendency: Tendency to overshoot final response.

AIRSPEED CONTROL: Was more burdensome than the best ones. In part because of imprecise pitch.

PERFORMANCE:

- Approach Tasks:
  - ILS: Pretty good, close attention required. Airspeed tended to be bothersome.
  - Visual (Sidestep): Sidestep easy.
- Landing Tasks: Landing performance was variable. If set up, it can be pretty good but if off nominal, it is difficult to correct.
- Differences: Trouble in both.

WIND AND TURBULENCE: Turbulence was bothersome. Probably caused pitch errors. Lat-Dir was very comfortable.

SUMMARY COMMENTS: Major problem was the airspeed control and the tendency to overshoot and make inaccurate pitch corrections. Have to make input, take it out and wait. If you try to force it, it tends to cause a pitch oscillation.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	B
Long	q_{med}	92.5	B	4.2	1.0	.87	18	A	RATING	7
									PIO	4

FLT/CONF.	613/3	WIND	Headwind	VISIBILITY	Clear
DATE	7/30/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Noticeable but not excessive, like a big airplane.
- Displacement: (Noticed tiny oscillations in roll feel system on occasion and nibbles in pitch feel).
- Sensitivity: Satisfactory.
- Trim: Didn't use trim a lot.

PITCH ATTITUDE RESPONSE:

- Initial: Not real happy with pitch response. Little bit sluggish.
- Predictability: Not satisfactory.
- Special Inputs: If you can set it up and leave it alone, it works real nice, but once I get down close to the ground, I can't leave my hands off it. I have no feel for how to select the final attitude and I can't bring myself to look inside at the ADI but I don't really have good feel outside for what attitude to choose.
- PIO Tendency: If I get in the loop, I get into an instability. A PIO of sorts.

AIRSPEED CONTROL: Reasonable but not great. Tended to fly fast.

PERFORMANCE:

- Approach Tasks:
  - ILS: Do reasonable ILS if you leave the airplane alone a lot.
  - Visual (Sidestep): Throttle can't be used closed loop, you set it and wait to see what happens. Standard settings don't always work out.
- Landing Tasks: Flare and touchdown was marginal, oscillating could cause damage if you hit at wrong time. Special technique is to try to get set up and fly open loop but I couldn't do it.
- Differences: Landing most difficult. Tend to close the loop and get into oscillation near the end.

WIND AND TURBULENCE: Hear and see turbulence but don't have to do anything.

SUMMARY COMMENTS: Major problem.- Tendency to overcontrol in flare.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	q_{Med}	92.5	C	4.2	1.0	.87	18	A	RATING	6
									PIO	4

FLT/CONF.	612/4	WIND	12 kt headwind	VISIBILITY	Clear
DATE	7/30/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Medium - light but in flare heavy.
- Displacement: Medium - but in flare larger.
- Sensitivity: Insensitive initially but steady state about right.
- Trim: Didn't use trim. No elevator required in turn.

PITCH ATTITUDE RESPONSE:

- Initial: Quite delayed.
- Predictability: IFR is adequate but in flare and touchdown it's not good.
- Special Inputs: If you try to hurry this airplane, tend to drive it into PIO.
- PIO Tendency: Tendency to PIO.

AIRSPEED CONTROL: Wasn't too bad.

PERFORMANCE: Fairly good.

- Approach Tasks:
  - ILS: Airspeed requires attention. Throttle response is terrible as usual. Not too much throttle activity required.
  - Visual (Sidestep): Sidestep easy although little loaded by sluggish pitch response.
- Landing Tasks: Flare and touchdown performance was where a problem comes in. Initial time delay tends to make you overdrive it in order to make it respond and you tend to overrotate. Sink rate at touchdown can't be positively controlled.
- Differences: Flare more difficult than approach.

WIND AND TURBULENCE: Airplane disturbed some in turbulence but it feels fairly solid. Turbulence disturbs the airplane laterally so need fair amount of attention on bank control.

SUMMARY COMMENTS: Major problem is flare and touchdown. Pitch response is so slow you can't control the flare and touchdown as well as I would like.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	q_{Hi}	92.5	A	4.2	1.0	.87	18	A	RATING	3
									PIO	1

FLT/CONF.	611/3	WIND	Headwind	VISIBILITY	Clear
DATE	7/29/80	TURB.	Moderate	AIRPORT	Buffalo

FEEL:

- Forces: Slightly heavy but desirable.
- Displacement: Slightly large but desirable.
- Sensitivity: Seemed about right, probably could have stood it a little lighter.
- Trim: Didn't use trim.

PITCH ATTITUDE RESPONSE:

- Initial: It was there, it's slow but I know what to do. Felt slow, but immediate in starting.
- Predictability: Good.
- Special Inputs: I don't overdrive it. No special input.
- PIO Tendency: None.

AIRSPEED CONTROL: Pretty good.

PERFORMANCE:

- Approach Tasks:
  - ILS: Good. I was very comfortable, relaxed, I knew what I was doing. Airspeed control was good, predictable.
  - Visual (Sidestep): Good. Could do sidestep.
- Landing Tasks: Flare and touchdown came out the way I wanted it, no special problems or control techniques. It's a big airplane though.
- Differences: No significant difference, neither was particularly difficult. Flare probably most demanding. I was more relaxed in the approach.

WIND AND TURBULENCE: Turbulence didn't seem to bother it. Crosswind easy to correct, naturally.

SUMMARY COMMENTS: Major problems - None. It's a big airplane and I had to fly it a little bit like one but it was pretty good.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	B
Long	q_{Hi}	92.5	A	4.2	1.0	.87	18	A	RATING	4
									PIO	3

FLT/CONF.	613/1	WIND	Headwind	VISIBILITY	Clear
DATE	7/30/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Forces were satisfactory when visual with small errors but during hooded ILS I felt the forces and displacements were heavy and large.
- Displacement: Heavy and large during hooded ILS.
- Trim: Trim was a little bit of a problem to keep the airspeed and attitude organized, but that may be my own lack of familiarization.
- Sensitivity:

PITCH ATTITUDE RESPONSE:

- Initial: Initial response was a little slow.
- Predictability: For the type of maneuvers I was doing it was generally slow but it was predictable.
- Special Inputs: None.

PIO Tendency: Some overcontrol in flare but not PIO.

AIRSPEED CONTROL: Airspeed required attention. Correlation between power settings I had and the airspeed seemed to change for last approach. The numbers I had sorted out before didn't seem to work on last approach.

PERFORMANCE:

- Approach Tasks:
  - ILS: Mediocre, moderately good. Trouble getting crosscheck organized.
  - Visual (Sidestep): No problem with sidestep.
- Landing Tasks: Problem in flare.
- Differences: No significant difference. Problems on ILS related to lack of familiarity with display arrangement.

WIND AND TURBULENCE: Turbulence and wind effects were significant. There is wallowing. Really don't notice the turbulence, especially at 2500 ft.

SUMMARY COMMENTS: Major problems - reasonable, stable airplane but precision of flight path and flare control in question. Not happy with my performance on the last one. Workload in turbulence was not greatly increased.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_I \sim p$	PILOT B
Long	q_{Hi}	92.5	A	4.2	1.0	.87	18	A	RATING 1 PIO 1

FLT/CONF.	615/2	WIND	Headwind	VISIBILITY	Clear
DATE	7/31/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Very nice.
- Displacement: Very nice.
- Sensitivity: Very nice.
- Trim: Stayed trim in turns.

PITCH ATTITUDE RESPONSE:

- Initial: Good.
- Predictability: Predictable.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Excellent. Once I get it trimmed up, it virtually holds the airspeed. It holds attitude and stays trimmed in turns. Airspeed control is the best I've seen.

PERFORMANCE:

- Approach Tasks:
  - ILS: As good as you want to make it.
  - Visual (Sidestep): Good, had sense of control.
- Landing Tasks: Good, you start thinking you can make a touchdown the way you want and when you want it. The good trim when you come into the flare is important.
- Differences: No significant differences.

WIND AND TURBULENCE: Not a factor.

SUMMARY COMMENTS: No major problems, an excellent airplane. At the risk of getting myself in a trap, but I really think it's an excellent airplane, it's a 1 as far as I'm concerned.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	B
Long	q_{Hi}	92.5	B	4.2	1.0	.87	18	A	RATING	2
									PIO	1

FLT/CONF.	613/4	WIND	Headwind	VISIBILITY	Clear
DATE	7/30/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Good.
- Displacement: Good.
- Sensitivity: Fine.

PITCH ATTITUDE RESPONSE:

- Initial: Satisfactory, when you calm down and just fly like I would fly a big airplane not like a fighter.
- Predictability: Quite predictable as long as you don't try to horse it too fast.
- Special Inputs: Back off and try to be precise but not aggressive.
- PIO Tendency: None.

AIRSPEED CONTROL: Quite good except for turbulence. I was quite high coming around on the last approach and was able to salvage it with some confidence.

PERFORMANCE:

- Approach Tasks:
  - ILS: As good as you want to make it.
  - Visual (Sidestep): Can manage it around sky instead of it managing me.
- Landing Tasks: Good performance. Felt more confident than others.
- Differences: No real differences.

WIND AND TURBULENCE: Crosswind - little problem getting it straight. I tend to want to put the wing down more than I need to. Can feel turbulence but don't need to do anything about it.

SUMMARY COMMENTS: No major problems. Good pitch control.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$1-Z_{\delta p}$	$\tau_1 \sim p$	PILOT A
Long	q_{Hi}	92.5	B	4.2	1.0	.87	18	A	RATING 3
									PIO 1

FLT/CONF.	617/1	WIND	Headwind	VISIBILITY	Very low, 1 mi
DATE	8/1/80	TURB.	Moderate, small cells and rain showers	AIRPORT	Niagara

FEEL:

- Forces: Medium to light.
- Displacement: Medium to small
- Sensitivity: All right.
- Trim: Didn't have to trim.

PITCH ATTITUDE RESPONSE:

- Initial: Response was there, no problems.
- Predictability: Seemed good.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Little tendency to get fast. Power setting required on first approach was 10% more than usual, then I tended to have a little too much on subsequent approaches.

PERFORMANCE:

- Approach Tasks:
  - ILS: Good.
  - Visual (Sidestep): Easy.
- Landing tasks: Overrotated a little on second appraoch, gust held it and it gradually sank down. No special control technique.
- Differences: Both easy.

WIND AND TURBULENCE: No particularly bad results.
Lat-Dir characteristics were good.

SUMMARY COMMENTS: No major problems. It's a big airplane and you have to plan ahead. It's basically a 2 airplane but the throttle control led me to the airspeed error problems so it's a 3.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT	A
Long	q_{Hi}	92.5	C	4.2	1.0	.87	18	A	RATING	5
									PIO	4

FLT/CONF.	612/2	WIND	12 kt headwind	VISIBILITY	Clear
DATE	7/30/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Relatively light. No force required in turn.
- Displacement: Modest, not large.
- Sensitivity: About right, little on light side.
- Trim: Didn't have to trim.

PITCH ATTITUDE RESPONSE:

- Initial: I'm confused, I don't know how to describe it. It doesn't want to hold whatever I gave it. It kind of drifted off the attitude I tried to put it to. Causes airspeed problems.
- Predictability: Predictability of final response is not good but not all that bad either.
- Special Inputs: No special technique.
- PIO Tendency: When I really try to peg it down in the flare and touchdown it seemed to oscillate a little bit. It's not like one of those I had earlier that I put something in and nothing happens. I feel something happen but for some reason I tend to overshoot it a little.

AIRSPEED CONTROL: Airspeed control was major attention requirement, fair, throttle response bothered me.

PERFORMANCE:

- Approach Tasks: Fairly good.
  - ILS:
  - Visual (Sidestep): Visual went fairly well. Sidestep easy.
- Landing Tasks: Flare performance was fair. I was oscillating in attitude a bit.
- Differences: About equal difficulty.

WIND AND TURBULENCE: Turbulence was there. Had feeling that when turbulence disturbed attitude, the airplane had no tendency to return. I had to push it back again.

SUMMARY COMMENTS: Major problems were airspeed control and just attitude control in general that require a lot of attention.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Long	q_{Hi}	32.5	A	4.2	1.0	.87	18	A	RATING 2-1/2 PIO 1

FLT/CONF.	627/4	WIND	5-10 kt tailwind	VISIBILITY	Very hazy
DATE	8/11/80	TURB.	Light-moderate	AIRPORT	Niagara

FEEL:
- Forces: Medium, not light.
- Displacement: Noticeable, not small.
- Sensitivity: Didn't think about changing, it wasn't bad.
- *Trim:* Didn't have to trim.

PITCH ATTITUDE RESPONSE:
- Initial: Fairly prompt initially but the final response takes a little while. It all seems to hang together and it came out all right in the flare and touchdown.
- Predictability:
- Special Inputs: None.
- PIO Tendency: No tendency.

AIRSPEED CONTROL: It takes a little bit of doing. It's fair.

PERFORMANCE:
- Approach Tasks:
  - ILS: Went well.
  - Visual (Sidestep): Heavy feeling but got desired performance.
- Landing Tasks: Didn't strike me as a super airplane but I have to admit it came out pretty good. No overrotation problems. No touchdown sink rate problems. No special control technique.
- Differences: Both went easy, relatively easy for big airplane anyway.

WIND AND TURBULENCE: Didn't seem to stir up motion very much. Lateral-Directional little on heavy side but adequate.

SUMMARY COMMENTS: No major problems. It's a trash hauler. Slow responding but reasonable precision in *flare and touchdown*, could get nose wheel lined up laterally. Could do the job with this big airplane. Speed control keeps it from being a 2, thrust response.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Long	q_{Hi}	32.5	A	4.2	1.0	.87	18	A	RATING 2 PIO 1

FLT/CONF.	631/6	WIND	Headwind	VISIBILITY	Havy in light rain
DATE	8/14/80	TURB.	Moderate	AIRPORT	Buffalo

FEEL:

- Forces: No problem.
- Displacement: No problem.
- Sensitivity: Increased gain, was little sluggish initially.

PITCH ATTITUDE RESPONSE:

- Initial: No problem.
- Predictability: Predictable.
- Special Inputs: Didn't feel I had to compensate, I felt I could fly in a natural fashion and use my hands and feet in a natural way.
- PIO Tendency: No.

AIRSPEED CONTROL: What you want to make it, in terms of concentration.

PERFORMANCE:

- Approach Tasks:
  - ILS: No problem.
  - Visual (Sidestep): No problem.
- Landing Tasks: Went back to my technique of chopping throttle at 40 ft or so and just flying the airplane in a natural fashion and I could do quite a precise job - good feeling of confidence.
- Differences: None.

WIND AND TURBULENCE: Nothing to report. Working a little harder to get the airplane lined up.

SUMMARY COMMENTS: No major problems, generally a good airplane. It is very difficult to dismiss from your mind some of your previous conceptions of the various configurations, the tail length and so on, you hear aft tail and say that should be better, you hear short tail and that should be worse --- I admit it's hard to dismiss them from your mind. Having made that excuse I still think it is a good airplane and I'll give it a 2 rating.

CANARD α AUGMENTATION PILOT COMMENT SUMMARIES

Unaug.	–	$T_1 = A$
Low α	–	$T_1 = A, B, C$
Med α	–	$T_1 = A, B, C$
High α	–	$T_1 = A, B, C$
Ex-High α	–	$T_1 = A$

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Canard	Unaug	140	A	4.2	--	.87	18	A	RATING	8 IFR 5 Land
									PIO	4

FLT/CONF.	627/3	WIND	7 kt tailwind	VISIBILITY	Very hazy
DATE	8/11/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: No steady elevator in turn. Get 10 kts fast you have a pull force. Force heavy during approach. Had gain increased.
- Displacement: Medium to large.
- Sensitivity: Pretty good after increased it.
- Trim: Very difficult to trim. Get your airspeed and the power set and trim for zero pitch rate. Didn't have time to really do all that.

PITCH ATTITUDE RESPONSE:

- Initial: IRR the initial response feels very delayed. In flare the initial response feels modestly prompt. Don't ask me what I mean by that, it's just what I see.
- Predictability: Poor predictability IFR, significantly better in flare.
- Special Inputs: Don't know.
- PIO Tendency: Very definite in up and away, low frequency PIO. Visually and in flare - not much tendency to PIO at all.

AIRSPEED CONTROL: Airspeed is very difficult, required lot of attention.

PERFORMANCE:

- Approach Tasks:
  - ILS: Surprisingly good, once I got steadied down. Terrible before that. Lots of attention required.
  - Visual (Sidestep): Lineup went well, not much vertical disturbance.
- Landing Tasks: Flare and touchdown was not too bad. Airspeed seemed better than on approach, still required a lot of attention.
- Differences: Approach was much more difficult than visual and landing.

WIND AND TURBULENCE: Turbulence was bothersome on approach. Lat-Dir. basically OK but heavy.

SUMMARY COMMENTS: Major problem is control of the airplane in pitch and flight path, vertical flight path when IFR or VFR in up away away flight.
Good features - lat-dir. Also pitch control in the flare was surprisingly better than in approach. It's an unstable configuration. I'll rate it separately for approach and for flare and touchdown.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Canard	α_{Lo}	140	A	4.2	--	.87	18	A	RATING 3
									PIO 2

FLT/CONF.	622/4	WIND	Headwind	VISIBILITY	Clear
DATE	8/6/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Medium. Could fly level turns without nose dropping or having to use back pressure.
- Displacement: Medium to small.
- Sensitiv ity: About right. Considered increasing but didn't. Didn't have to trim.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response felt like it was there. It's a slow response but I seem to know that it was there.
- Predictability: Fairly good, considering it was as long as it was.
- Special Inputs: No.
- PIO Tendency: No.

AIRSPEED CONTROL: Airspeed control looked good.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope and localizer were very good. Airspeed was not a problem. Thrust lags didn't bother me, didn't have to keep resetting throttles.
  - Visual (Sidestep): Good.
- Landing Tasks:
- Differences:

First flare and touchdown was not quite what I wanted. I over-rotated and landed long. Second landing was pretty darn good. I don't feel the ponderous delay that I had sensed with other configurations. No special inputs other than being careful not to over-rotate.

WIND AND TURBULENCE: Moderate turbulence was no problem. Lat-dir was good factor.

SUMMARY COMMENTS: Major problem - Hate to call it a major problem, but flight path response in the flare was a little ponderous, had to be careful not to over-rotate.
Good features - lat-directional and speed control didn't seem to be a particular problem.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Canard	α_{Lo}	140	B	4.2	--	.87	18	A	RATING 6
									PIO 3

FLT/CONF.	621/3	WIND	Headwind	VISIBILITY	Very Hazy
DATE	8/5/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: Heavy in maneuvering, not so much so in steady turn.
- Displacement: Large.
- Sensitivity: Thought about reducing it but then the steady force and the steady turn was reasonable so I didn't.
- Trim: Didn't use trim.

PITCH ATTITUDE RESPONSE:

- Initial: Seemed delayed.
- Predictability: Predictable enough but not comfortable. Not sure where it's going to go. Can do the job though.
- Special Inputs: Overdrive to get it going.
- PIO Tendency: Not really a PIO, but undesirable motion in flare and touchdown.

AIRSPEED CONTROL: Difficult but didn't have as much tendency to get slow as on last one. Required attention probably because there is a loose connection between me and the attitude of the airplane. Don't have good positive control of attitude.

PERFORMANCE:

- Approach Tasks:
  - ILS: Lost localizer and glide slope control precision in close. It heaves and goes off and then it's ponderous to get back. Sluggish thrust response.
  - Visual (Sidestep):
- Landing Tasks: Could be done acceptably but was not comfortable. If you get off, it's ponderous to get back.
- Differences: Not much difference.

WIND AND TURBULENCE: Turbulence had an effect on the airplane and it takes a while to get back. Especially it had a heave effect. Roll seemed heavy at times.

SUMMARY COMMENTS: Major problem is kind of a ponderous pitch response. Rating is a 5-1/2 or 6. I'll call it a 6 but maybe a little severe.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT	B
Canard	α_{Lo}	140	C	4.2	--	.87	18	A	RATING	4-1/2
									PIO	1

FLT/CONF.	616/1	WIND	11 kt headwind	VISIBILITY	Very hazy, IFR
DATE	8/1/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: The feel - I did make a change in sensitivity, don't really think it made much difference. The airplane tends to wander in pitch attitude. I had a little difficulty trimming.
- Displacement:
- Sensitivity:

PITCH ATTITUDE RESPONSE:

- Initial: When I was actively controlling pitch attitude, it seemed predictable enough but it seemed to wander and didn't hold a trim attitude very well.
- Predictability:
- Special Inputs:
- PIO Tendency: No.

AIRSPEED CONTROL: Not very good. Because of traffic control, we started the approach with unusual initial conditions. So I was high all the time and throttle management when you have to make large throttle changes is difficult to get the right number. In general, because of wandering in pitch, the airspeed control was not too good.

PERFORMANCE:

- ILS: ILS and localizer was reasonable. I had to work at it because of attitude wander.

  Visual (Sidestep): Didn't really do a visual approach. Actual IFR down to 600-800 feet. It was no problem except for having to manage a high to start with.
- Landing Tasks: Flare and touchdown was real easy. I seemed to have really good control with very tiny inputs and it's quite pleasant. No special inputs, I can fly it naturally.
- Differences: Approach was more difficult than the landing.

WIND AND TURBULENCE: More noticeable turbulence in terms of ride qualities on this flight but I'm not actively having to do anything about it. Crosswind was easy to contend with.

SUMMARY COMMENTS: Major problem was tendency to wander in attitude and required a lot of trim activity on approach. Overall, I would give it a 4-1/2. The half is because I have to work a little harder than I wanted to on the approach. If I rated it just under 50 ft, it would be at least a 3.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Canard	α_{Lo}	140	C	4.2	--	.87	18	A	RATING 6
									PIO 3

FLT/CONF.	616/5	WIND	11 kt headwind	VISIBILITY	Very hazy, IFR
DATE	8/1/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:
- Forces: No complaint.
- Displacement: No complaint.
- Sensitivity: No complaint.

PITCH ATTITUDE RESPONSE:
- Initial: Initially I noticed a tendency to oscillate slightly, overcontrol. But during the actual flying I didn't notice anything that I would say was oscillatory. I did have more difficulties in general and I don't have a good feeling as to why that was. Can't discuss anything about the initial response.
- Predictability: Predictability was degraded and I think that bothered me to some extent on the approaches.
- PIO Tendency:

AIRSPEED CONTROL: Airspeed was ragged.

PERFORMANCE:
- Approach Tasks:
  - ILS: Not very good. Had to work at it and not sure why.
  - Visual (Sidestep): Can do OK.
- Landing Tasks: Can do in natural way but I did lousy on the first approach. Had troubles with lineup and then put in an input because I was going to land short, but I tried to extend a little bit and I ended up at 20 ft for a long time. No oscillation, just going long.
- Differences: Approach may have been a little more trouble. The airplane was sloppy, I didn't like the approach

WIND AND TURBULENCE: Had trouble with crosswind correction. Turbulence causes noticeable ride qualities and airspeed thrashing around, but nothing that I feel I have to control.

SUMMARY COMMENTS: Major problem - Have to work too hard. Maybe I'm tired but I just worked too hard with this airplane. Didn't feel confident with it. Mainly inexactness in pitch.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Canard	α_{Lo}	140	C	4.2	--	.87	18	A	RATING 6 PIO 3

FLT/CONF.	620/2	WIND	Headwind	VISIBILITY	Hazy
DATE	8/5/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Medium, heave side in maneuvers.
- Displacement: --
- Sensitivity: About right.
- Trim: Didn't do much trim.

PITCH ATTITUDE RESPONSE:

- Initial: Sluggish and ponderous.
- Predictability: IFR was reasonably predictable. Once you get it there it tended to stay.
- Special Inputs: Overdrive it especially in flare.
- PIO Tendency: None on approach but there was in flare and touchdown.

AIRSPEED CONTROL: Tended to lose airspeed in landing.

PERFORMANCE:

- Approach Tasks:
  - ILS: Pretty good.
  - Visual (Sidestep): Easy.
- Landing Tasks: Difficult to flare. Slow and sluggish and unresponsive flight-pathwise. You have a tendency to overdrive it and start a little oscillation. Can feel something happening.
- Differences: Flare and touchdown is most difficult.

WIND AND TURBULENCE: Less effect of turbulence, doesn't disturb attitude. Crosswind easy. Lat-Dir. good.

SUMMARY COMMENTS: Major problem in flare, not being able to do as well as I want, not well behaved.
Could definitely feel whenever I put a control input in, I could feel the acceleration in the cockpit. It certainly did give me an alerting cue that I was putting something in. In the flare you have a small PIO going but you do have the alerting cues of acceleration in the cockpit when you put an input in, even though you don't see the attitude response particularly. You feel something going on so you don't tend to overdo it as much as I have with some.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Canard	α_{Med}	140	A	4.2	--	.87	18	A	RATING	4-1/2
									PIO	1

FLT/CONF.	621/2	WIND	Headwind	VISIBILITY	Very hazy
DATE	8/5/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: Medium
- Displacement: Medium to smallish
- Sensitivity: About right.
- Trim: Didn't really use trim.

PITCH ATTITUDE RESPONSE:

- Initial: Reasonably prompt for a big airplane.
- Predictability: Quite predictable.
- Special Inputs: No special input, except remember to look at airspeed everytime you change angle of attack and do something with the thrust.
- PIO Tendency: None.

AIRSPEED CONTROL: Difficult. Seems like you have a high induced drag type configuration, maybe even on backside of the power curve. slipperyness in airspeed, when you're slow you tend to stay slow and takes extra thrust to get it coming back. When you're fast, it's hard to get slowed back down again.

Visual (Sidestep): Sidestep easy.

- Landing Tasks: Flare and touchdown was easy and predictable. No special control technique.
- Differences: Speed control was problem. Visual circling approaches were more difficult because we were changing angle of attack so I had an additional variable to worry about. Had to worry about how much "g" I was pulling and what kind of airspeed errors I had.

WIND AND TURBULENCE: Reasonably insensitive to turbulence. Little attitude change when hit by gust.

SUMMARY COMMENTS: Major problem was airspeed control. Good feature is the pitch control especially in flare and touchdown.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Canard	α_{Med}	140	B	4.2	--	.87	18	A	RATING 5 Appr, 3 Land. PIO 1

FLT/CONF.	616/2	WIND	11 kt headwind	VISIBILITY	Very hazy, IFR
DATE	8/1/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:
- Forces: No complaints.
- Displacement: No complaints.
- Sensitivity: No complaints.

PITCH ATTITUDE RESPONSE:
- Initial: If I look at the response and predictability of changing an attitude, it's reasonable. It's just the long term sort of trimmability or holding an attitude is not good.
- Special Inputs:
- PIO Tendency: No

AIRSPEED CONTROL: Not satisfactory on approach.

PERFORMANCE:
- Approach Tasks:
  - ILS: Not really satisfactory in sense I had to work too hard. The airplane just doesn't handle precisely on the approach. I just can't nail things down, seems to be a lot more airspeed fluctuations. Actual IFR down to about 800 ft.
  - Visual (Sidestep): Had little more trouble sorting out lineup today than on previous days.
- Landing tasks: Flare and touchdown performance was excellent. I could select where I wanted to land, felt I knew what I was doing. Could land about prescribed point with reasonable sink rate.
- Differences: Approach is more difficult.

WIND AND TURBULENCE: Had little more difficulty getting the crosswind out, getting a stabilized heading, required some directional effort near the end that I don't like to have to do. No problem with roll control, little problem getting the directional rudder requirements sorted out and stabilized.

SUMMARY COMMENTS: Major problem is just lack of precision in flying the approach very precise in the landing task. Just not solid on approach and airspeed control wandering. It's very difficult because of the power control lags, you have to be constantly working the throttles. I only achieved adequate performance on the approach, and I'd give it a 5 rating. The landing itself was much better than that. I would be satisfactory from 50 ft on in.

TAIL	AUG.	$\tau_{F_{C.R.}}$	$\tau_I \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_I \sim p$	PILOT A
Canard	α_{Med}	140	B	4.2	--	.87	18	A	RATING 5
									PIO 3

FLT/CONF.	620/3	WIND	Headwind	VISIBILITY	Hazy
DATE	8/5/80	TURB.	Light and moderate	AIRPORT	Niagara

FEEL:

- Forces: Heavy
  Big airplane-like.
- Displacement: Large
- Sensitivity: Maybe should have been a little higher. Turns are the thing I don't like very much.

PITCH ATTITUDE RESPONSE:

- Initial: Slow and sluggish IFR. Moderate in flare. The flight path does not necessarily respond all that well but I get a feeling here in the cockpit that when I put something in, something happens.
- Predictability: Predictability of final response is better visually than it is IFR but it's certainly adequate IFR.
- Special Inputs: You have to anticipate some wandering in the pitch and pay attention to correcting it before an altitude deviation.
- PIO Tendency: Didn't really see a PIO.

AIRSPEED CONTROL: Airspeed control was variable. Thrust response is really crappy, I don't like it. Have to check throttle position relative to reference marks. Don't have same reference position today that I had yesterday.

PERFORMANCE:

- Approach Tasks:
  - ILS: Approach performance was reasonably good. Attitude is kind of loose and you have the feeling of a delay when you're flying through the attitude indicator.
  - Visual (Sidestep): Sidestep went well.
- Landing Tasks: Flare and touchdown is not easy. You're behind the airplane in making corrections. Special technique is to stay on top of it. I found I was using fairly tight elevator inputs and I had some perception I think in the seat of my pants that I was getting a response before I even saw it in the attitude or flight path.
- **Differences:** Approach and flare were about equal difficulty.

WIND AND TURBULENCE: Not unduly sensitive to turbulence. Crosswind easy. Airplane is ponderous in yaw, have to anticipate crosswind correction. Put in early if pitch control is poor.

SUMMARY COMMENTS: Major problem is pitch control.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Canard	α_{Med}	140	C	4.2	--	.87	18	A	RATING 6
									PIO 4

FLT/CONF.	622'2	WIND	Headwind	VISIBILITY	Clear
DATE	8/6/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Medium.
- Displacement: Medium to small.
- Sensitivity: About right.
- Trim: Didn't have to trim.

PITCH ATTITUDE RESPONSE:

- Initial: Feels delayed.
- Predictability: Less than good. Not as much problem on ILS. Problem is in flare.
- Special Inputs: Tend to overdrive it.
- PIO Tendency: None up and away. Some in flare and touchdown.

AIRSPEED CONTROL: Not a major problem. Airspeed problem in landing were caused by pitch control and running out of energy.

PERFORMANCE:

- Approach Tasks:
  - ILS: Fairly good. Airspeed fair.
  - Visual (Sidestep): Lineup good.
- Landing Tasks: Bigger problems in flare, the airplane feels ponderous. I can feel things happening in the cockpit when I use the elevator but it doesn't seem to cure the problem of keeping me from inaccurately rotating and then having to make flight path corrections to achieve touchdown. Best way to land this one is to get it set up and let it land itself. When I get in the loop, things start to degrade.
- Differences: There is a significant difference between approach and landing and landing is more difficult.

WIND AND TURBULENCE: Turbulence not a significant factor. Lat/Dir. were good.

SUMMARY COMMENTS: Major problem was the pitch control in the flare and touchdown. Some tendency to PIO and inaccurate flare and touchdown.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Canard	α_{Hi}	140	A	4.2	--	.87	18	A	RATING 3
									PIO 1

FLT/CONF.	616/3	WIND	11 kt headwind	VISIBILITY	Very hazy, IFR
DATE	8/1/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:
- Forces: OK.
- Displacement: OK.
- Sensitivity: OK.
- Trim: Trimup satisfactory.

PITCH ATTITUDE RESPONSE:
- Initial: Good.
- Predictability: Good.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Varied a bit. I think partly because of turbulence we are operating in.

PERFORMANCE:
- Approach Tasks:
  - ILS: Good. Can hold attitude and make corrections in a predictable fashion.
  - Visual (Sidestep): Having more lineup problems than I've seen before.
- Landing Tasks: You can nail the touchdown point, at least you had a feeling of confidence you've got things under control. Airspeed didn't seem to disappear as rapidly as some, likely because you're under better control. Flare and touchdown I thought was real easy, no special control technique. Could fly very naturally and you can integrate throttle and hands very naturally with this airplane. There is no feeling that you want to chop the throttle at a given altitude and do it open loop. You can do in a very natural fashion.
- Differences:

WIND AND TURBULENCE: Turbulence effect on airspeed is noticeable. Crosswind alignment seemed more difficult today.

SUMMARY COMMENTS: No major problems.

TAIL	AUG.	$X_{p_{C.R.}}$	$\dot{t}\sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1\sim p$	PILOT A RATING 4 PIO 1
Canard	α_{Hi}	140	A	4.2	--	.87	18	A	

FLT/CONF.	62C/1	WIND	Headwind	VISIBILITY	Hazy
DATE	8/5/80	TURB.	Light and moderate	AIRPORT	Niagara

FEEL:

- Forces: Medium
- Displacement: Smallish side compared to what I frequently see.
- Sensitivity: About right.
- Trim: Had some problems trimming after initial engage. Have new throttle position and thrust for level flight.

PITCH ATTITUDE RESPONSE:

- Initial: Relatively prompt.
- Predictability: The final response isn't bad except that the damn thing doesn't seem to want to stay there. In turbulence I had to keep careful count of the pitch attitude and keep it back where it belongs and it requires workload.
- Special Inputs:
- PIO Tendency: No PIO.

AIRSPEED CONTROL: Fair. Airspeed problems are probably related to attitude problem.

PERFORMANCE:

- Approach Tasks:
  - ILS: Pretty good but moderate workload. Airspeed control was reasonable on second ILS.
  - Visual (Sidestep): Easy.
- Landing Tasks: Feel you have reasonably positive control of pitch and flight path in flare and touchdown. It's a big slow airplane.
- Differences: Approach was perhaps a little more difficult. Requires attention to attitude.

WIND AND TURBULENCE: Effects of turbulence were objectionable on pitch in the ILS. Lat-Dir seemed good.

SUMMARY COMMENTS: No major problems but pitch control in turbulence and resulting airspeed and altitude errors were workload producing.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Canard	α_{Hi}	140	A	4.2	--	.87	18	A	RATING 6 PIO 3

FLT/CONF.	621/4	WIND	Headwind	VISIBILITY	Very hazy
DATE	8/5/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: Heavy until increased gain by 1.32,then medium.
- Displacement: Large before gain increase. Then medium.
- Sensitivity: Low before gain increase, then good choice.
- Trim: Trim was difficult to achieve.

PITCH ATTITUDE RESPONSE:

- Initial: Initially delayed.
- Predictability: Poor especially in turns. Can't figure out what to do with the elevator to make a level turn. Had trouble both IFR and also VFR in 360° turn. Had poor visibility.
- Special Inputs: Lot of attention to pitch attitude. Seemed like I had to use a lower pitch attitude in the turn than straight and level. Correspondence between pitch attitude and rate of descent didn't seem right.
- PIO Tendency: No PIO.

AIRSPEED CONTROL: Very difficult on most of approaches except the last part of the last one after we reengaged following a dump.

PERFORMANCE:

- Approach Tasks:
  - ILS: Not all that bad. Airspeed and throttle control were difficult, especially in turns. Altitude control was a problem in ILS.
  - Visual (Sidestep):
- Landing Tasks: Could land reasonably well.
- Differences: Approach was more difficult than landing. Airspeed and altitude control problems in approach.

WIND AND TURBULENCE: It was turbulent. It is hard to separate out whether the turbulence was causing some of my problems with airspeed and altitude control, don't think so. There just didn't seem to be a correspondence between airspeed and rate of climb.
Lat-Dir. appeared good.

SUMMARY COMMENTS: Major problem was airspeed and rate of climb control in IFR and general maneuvering VFR. Not sure the model following system was working on this one, until the last landing. (Note: Model following was working properly. Problems were due to turbulence effects).

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Canard	α_{Hi}	140	A	4.2	--	.87	18	A	RATING	4
									PIO	2

FLT/CONF.	622/1	WIND	Headwind	VISIBILITY	Clear
DATE	8/6/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Medium. Feels heavy in steeper turns. Steady elevator is required in a steady turn. For approach, forces are medium.
- Displacement: Medium. Feel large in steeper turns.
- Sensitivity: Reasonable.
- Trim: Had to trim at least once during the first approach. Relatively easy to do.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed.
- Predictability: Fair.
- Special Inputs: Overdrive a little if in a hurry.
- PIO Tendency: None.

AIRSPEED CONTROL: Fair, not glued but didn't notice being off more than 5 kts.

PERFORMANCE:

- Approach Tasks:
  - ILS: Reasonably good. Some tendency to get off glide slope in turbulence because of difficulty holding precise attitude. Possibly related to breakout forces. Airspeed on ILS was fair.
  - Visual (Sidestep): Sidestep was easy.
- Landing Tasks: Flare and touchdown was relatively easy for a big airplane. You have to stay ahead of them and worry about your airspeed decay if you're taking longer in the flare. No special control technique in flare.
- Differences: No big difference in difficulty.

WIND AND TURBULENCE: Turbulence was objectionable factor in approach.

SUMMARY COMMENTS: Bank angle control was good, no sideslip induced by roll control. Slow to trim sideslip. No major problems. Pitch attitude control was ponderous and a little springy.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Canard	α_{H1}	140	B	4.2	--	.87	18	A	RATING	5
									PIO	3

FLT/CONF.	622/3	WIND	Headwind	VISIBILITY	Clear
DATE	8/6/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:
- Forces: Heavy at beginning then we increased the gain by 1.32 and the forces were definitely improved. Medium.
- Displacement: Medium.
- Sensitivity: Good after increase.
- Trim: Didn't trim.

PITCH ATTITUDE RESPONSE:
- Initial: Little delayed.
- Predictability: Adequate everywhere except close to the ground.
- Special Inputs: None.
- PIO Tendency: None. Had inaccurate flight path control in flare.

AIRSPEED CONTROL: Fairly good. Relaxed more than with most.

PERFORMANCE:
- Approach Tasks:
  - ILS: Pretty good, but high workload in turbulence close in.
  - Visual (Sidestep): Easy.
- Landing Tasks: Ponderous feeling in the flare. I don't really PIO it but I twice over-rotated it. I didn't mean to but I was holding off and perhaps there is some learning involved in the configuration.
  That's one of the difficult things with only three landings and if the third one comes out better than any of the others, I never know whether it's me learning or an accident. Special control technique, I think a minimum of me in the loop.
- Differences: Flare and touchdown was the more difficult.

WIND AND TURBULENCE: Turbulence effects were not as strong as on others. Lat-Dir characteristics were good.

SUMMARY COMMENTS: Major problem is the inaccurate control of vertical flight path in the flare and touchdown.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Canard	α_{Hi}	140	C	4.2	--	.87	18	A	RATING 5
									PIO 1

FLT/CONF.	616/4	WIND	11 kt headwind	VISIBILITY	very hazy, IFR
DATE	8/1/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: When I first got the airplane I thought it was unstable in pitch but it never really materialized.
- Displacement: Didn't have to use big inputs.
- Sensitivity: Satisfactory.

PITCH ATTITUDE RESPONSE:

- Initial: Satisfactory.
- Predictability: Didn't notice any lack of predictability.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Had some difficult initial conditions to contend with and some problems with lineup more than I really understand. Anticipate a crosswind on last approach that never occurred.

PERFORMANCE:

- Approach Tasks:
  - ILS: Airspeed was a little difficult. Little work required there. ILS OK. Last one difficult because of initial conditions.
  - Visual (Sidestep):
- Landing Tasks: Some trouble with lineup because I thought we were going to have a crosswind.
- Differences: No real difference. Work a bit harder on approach. Not a real confident feeling. Not a solid feeling with the trim on approach. Minor problems.

WIND AND TURBULENCE: Notice the banging around in real turbulence. Notice some low frequency problems in response to rudder.

SUMMARY COMMENTS: Major problems - Nothing outstanding. Lineup problems and moderate workload in controlling pitch on approach. Nothing really stands out as bad but I wasn't able to do a real solid job.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Canard	α_{Hi}	140	C	4.2	--	.87	18	A	RATING 5
									PIO 3

FLT/CONF.	621/1	WIND	Headwind	VISIBILITY	Very hazy
DATE	8/5/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: Requires elevator in steady turn, caused me to ask for higher gain by 1.32. Heavy → medium.
- Displacement: Moderate → noticeable smaller after gain change.
- Sensitivity: Like the increased gain better.
- Trim: Didn't use trim.

PITCH ATTITUDE RESPONSE:

- Initial: IFR it feels delayed. VFR not terribly delayed.
- Predictability: Not too bad. It's ponderous and slow but not terrible.
- Special Inputs: Have to worry about using throttle properly.
- PIO Tendency: Tendency toward PIO in flare and touchdown but it's bounded and tolerable.

AIRSPEED CONTROL: Tended to get slow. Learning required. Put power on in turn and take off when you roll level. Induced drag.

PERFORMANCE:

- Approach Tasks:
  - ILS; Good ILS and Localizer, airspeed wasn't a particular problem but thrust response was always a problem.
  - Visual (Sidestep): Sidestep was easy.
- Landing Tasks: Tended to oscillate in pitch but was able to achieve adequate performance. No special technique.
- Differences: About equal difficulty. Ponderous on approach and a little delayed in flare.

WIND AND TURBULENCE: Turbulence not a major factor. Lat-Dir. was basically good.

SUMMARY COMMENTS: Primary problem was flare and touchdown resulted in pitch oscillations and airspeed in turns. Poor thrust response.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Canard	α_{ExHi}	140	A	4.2	--	.87	18	A	RATING 5
									PIO 2

FLT/CONF.	630/1	WIND	6 kt headwind	VISIBILITY	Partly cloudy & slightly hazy
DATE		TURB.		AIRPORT	Niagara

FEEL:

- Forces: Heavy until I asked for a gain increase, then they still felt heavy, especially in the turn and also for flight path corrections so I asked for further gain increase. The forces were then medium.
- Displacement: Displacements were large in turning flight.
- Sensitivity: Increased two times.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response was very prompt, very noticeable in terms of acceleration at the cockpit. I felt I had attitude changes too.
- Predictability: So the initial response was prompt but predictability of the final response was fair. Seemed like there was a bit of response tail in that the initial response felt very prompt and quick but the final response took a fair length of time to finish. It made the airplane feel initially quick but ponderous flight path response.
- Special Inputs: No special inputs.
- PIO Tendency: No PIO.

AIRSPEED CONTROL:

PERFORMANCE:

- Approach Tasks:
  ILS: Airspeed pretty good but high workload. It seems like I'm either on the backside or bottomside where the airplane is -- when it gets fast, it takes extra input to get it back and if you don't catch it, then it gets too slow, if you don't catch it promptly. The same way if you get slow, it takes a lot of extra throttle to get it back. If you don't catch it when you're right on, you end up getting fast. So on the glide slope I had trouble getting high and fast.

  Visual (Sidestep): Visual sidestep was easy, vertical flight path wasn't a problem.
- Landing Tasks: Flare and touchdown - if you fly it tightly, you get *good perception of your inputs.* You don't over-control it and you can kind of slap it around and get it to come out fairly decently.
- Differences: Approach was higher workload.

WIND AND TURBULENCE: Turbulence increases workload. Lat-dir. -- little heavy.

SUMMARY COMMENTS: Major problems - ponderous airplane to maneuver, especially IFR. But also visually in the approach. Airspeed was real difficulty. Flare goes easier. Airspeed control and flight path control away from ground were

the problem. Pilot noted the sink rate he perceived was lower than callout at T.D..

I definitely perceive the normal acceleration environment in the cockpit when I use the elevator control. It gives me a good perception of the fact that I'm making an input.

When I make an elevator input, I get a perception that I made an input but then flight path or attitude or whatever the hell it is that changes, come on later so it's not a real pleasant configuration. It's almost too much normal acceleration cues.

CANARD q AUGMENTATION — PILOT COMMENT SUMMARIES

High q ($X_{PCR} = 140'$) — $T_1 = A$
High q ($X_{PCR} = 80'$) — $T_1 = A$

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Canard	q_{Hi}	140	A	4.2	1.0	.87	18	A	RATING 3 PIO 1

FLT/CONF.	627/2	WIND	7 kt tailwind	VISIBILITY	Very hazy
DATE	8/11/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Medium to a little on the light side. No force in turn.
- Displacement: Small.
- Sensitivity: Good.
- Trim: No use of trim.

PITCH ATTITUDE RESPONSE:

- Initial: Very prompt.
- Predictability: Pretty good except a little tendency to overrotate on the flare.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Fair, not good but not a problem.

PERFORMANCE:

- Approach Tasks:
  - ILS: Good, airspeed fair.
  - Visual (Sidestep): Lineup was easy, no problem with pitch flight path.
- Landing Tasks: Flare and touchdown - very prompt airplane, feel like I'm out on the end of a long road and, if anything, I might have used a little bit more learning with this configuration. Then I might have liked it even better. Had a little tendency to overrotate.
- Differences: Approach and landing were about the same difficulty.

WIND AND TURBULENCE: Turbulence was not a significant factor.

SUMMARY COMMENTS: Lat-Dir seemed heavier than I'd like. Major problems - No major problems, just not quite as good touchdown control as I think I'd like. Probably could learn it real well. Almost rated it a 2.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Canard	q_{Hi}	80	A	4.2	1.0	.87	18	A	RATING	3
									PIO	1

FLT/CONF.	627/1	WIND	7 kt tailwind	VISIBILITY	Very hazy
DATE	8/11/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Forces were heavy so increased gain by factor 1.46 and that seemed to help. No steady force in turn.
- Displacement: Medium to small.
- Sensitivity: Liked the increase gain.
- Trim: Did not trim.

PITCH ATTITUDE RESPONSE:

- Initial: Fairly prompt.
- Predictability: Fairly good but want to note that I did overrotate on a couple of touchdowns. It wasn't a very big overrotation.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Some attention was required to establish the reference thrust settings for this configuration. It wasn't the best for airspeed control.

PERFORMANCE:

- Approach Tasks:
  - ILS: Quite good ILS and localizer. Airspeed fair quality at best.
  - Visual (Sidestep): Sidestep was easily performed, did not have trouble with the pitch flight path.
- Landing Tasks: Not a whole lot of flare required but what was needed could be provided with the elevator without any tendency to oscillate in pitch. Little tendency to overrotate and hold off a little bit. No special control technique.
- Differences: No significant difference between approach and landing.

WIND AND TURBULENCE: Turbulence not a problem.

SUMMARY COMMENTS: Lat-Dir was a little heavy, more than reference. Major problem - None. Just a little bit of a tail in the longitudinal response that was a little difficult to predict and made me have a tendency to overrotate and balloon just a bit. Airspeed control required attention which was probably more than minimal.

SHORT AFT TAIL α AUGMENTATION — PILOT COMMENT SUMMARIES

Med α — $T_1 = A, B$

High α — $T_1 = A, B$

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Short	α_{Med}	-10	A	4.2	--	.87	18	A	RATING 10 PIO 5

FLT/CONF.	619/2	WIND	5-10 kt tailwind	VISIBILITY	Clear
DATE	8/4/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Moderate to heavy.
- Displacement: Moderate.
- Sensitivity: About right.
- Trim: Didn't use trim.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed and sluggish.
- Predictability: Fair in up and away and extremely difficult in flare and touchdown.
- Special Inputs: Not sure.
- PIO Tendency: Definite tendency to PIO in the last few feet before touchdown. It's a bad configuration, you think you have it set up pretty well and then you get into trouble.

AIRSPEED CONTROL: Somewhat difficult, seemed to bleed without giving me any awareness.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope was not operating. Localizer was reasonable. Airspeed demanding.
  - Visual (Sidestep): Sidestep went fine. Final part of approach seemed to go ponderously but O.K., but anytime you need a flight path correction close in, it just seemed to be extremely difficult to make.
- Landing Tasks: Flare and touchdown was extremely difficult, you tended to PIO.
- Differences: Extremely big difference - it just felt heavy in the approach whereas in the flare and touchdown, it was very imprecise and you oscillated when you tried to produce touchdown conditions. By far, the flare and touchdown was most difficult.

WIND AND TURBULENCE: Turbulence probably was a factor. Crosswind not a problem. Lat-Dir. was good.

SUMMARY COMMENTS: Major problem - was the flight path control in pitch in flare and touchdown. Get flight path PIO in last few feet.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B RATING 10 PIO 6
Short	α_{Med}	-10	B	4.2	--	.87	18	A	

FLT/CONF.	615/4	WIND	Headwind	VISIBILITY	Clear
DATE	7/31/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: No complaints.
- Displacement: No complaints.
- Sensitivity: No complaints.

PITCH ATTITUDE RESPONSE:

- Initial: No real complaints when you are above 50 ft.
- Predictability: Poor, I did notice even on approach a little nibble of an oscillation on occasion. Oscillations were small on approach and controllable.
- Special Inputs: Tone down your inputs, not be aggressive.
- PIO Tendency: PIO Tendency, on approach very mild, in landing very severe.

AIRSPEED CONTROL: Satisfactory on approach. Lousy in flare.

PERFORMANCE:

- Approach Tasks:
  - ILS: Good.
  - Visual (Sidestep): Good down to 50 ft.
- Landing Tasks: Flare is major problem. I can't get the airplane organized below 50 ft.
  Some of the characteristics interfere with my ability to precisely control the approach to get in the window correctly.
- Differences: Landing was clearly the worst task.

WIND AND TURBULENCE: Turbulence was detracting factor Couldn't find a special technique that worked.

SUMMARY COMMENTS: Major problem. Lack of predictability in pitch and a great deal of difficulty in controlling and predicting the touchdown point and sink rate, mostly the sink rate, Down to 50 ft it is quite manageable. I could fly it rather precisely, under 50 ft I cannot get the airplane organized. Severe PIO in the flare.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Short	α_{Med}	-10	B	4.2	--	.87	18	A	RATING	10
									PIO	5

FLT/CONF.	618/5	WIND	5-10 kt tailwind	VISIBILITY	Clear
DATE	8/4/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Steady state the forces are medium but in PIO they get modertae to heavy.
- Displacement: Tend to get large in PIO.
- Sensitivity: Pretty good choice.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed.
- Predictability: Very difficult.
- Special Inputs: Have to anticipate that it is going to be a delayed response. Make corrective inputs in opposition to nose rate. Compensation control is complex.
- PIO Tendency: Very definite tendency to PIO both IFR and VFR but it's very much worse VFR.

AIRSPEED CONTROL: Difficult.

PERFORMANCE:

- Approach Tasks:
  - ILS: High workload in pitch and tended to oscillate. Localizer not bad, not much time for it. Airspeed high workload.
  - Visual (Sidestep): Tend to forget about sidestep.
- Landing Tasks: It's bad in flare and touchdown. It's a PIO bugger. You can develop a technique that helped by keeping deviations small and putting in elevator inputs, pulse inputs in opposition to pitch rate. Very high workload.
- Differences: Flare and touchdown most difficult. Lat-Dir. characteristics are good.

WIND AND TURBULENCE: Turbulence is bothersome, takes long time to correct disturbances.

SUMMARY COMMENTS: Major problem - PIO in flare. Just a matter of time 'til you kill yourself in this one. PIO doesn't get divergent until flare.
Good feature - Lat-Dir.
Below 350 ft the PIO started, all I had to do was look at the ground and I was in a PIO.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Short	α_{Hi}	-10	A	4.2	--	.87	18	A	RATING 10
									PIO 4

FLT/CONF.	615/3	WIND	Headwind	VISIBILITY	Clear
DATE	7/31/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: No complaints, little aft stick in turns.
- Displacement: No complaints.
- Sensitivity: No complaints.

PITCH ATTITUDE RESPONSE:

- Initial: Good, except right down near the ground.
- Predictability:
- Special Inputs:
- PIO Tendency:

AIRSPEED CONTROL: Reasonable until last 20 ft, unacceptable in last 20 ft.

PERFORMANCE:

- Approach Tasks:
  - ILS: No problem, you can fly perfect ILS in this airplane.
  - Visual (Sidestep): Everything O.K. down to 20-25 ft.
- Landing Tasks: Flare and touchdown performance was very poor.
- Differences: Tried several control techniques. First, I flew in a normal fashion and that didn't work. I could really feel myself ballooning and getting into a position where I knew the next oscillation was going to be a crunch and there wasn't anything I could do about it. I knew that I was putting my wheels down harder as I pulled back. The second one I was high and ended up with high sink rate and long. I then tried to not make any big changes close in. So I'm going to come in and duck under just a little bit and come in low and make a change and hold it. I attempted to do that and came close to making it, but ended up at about 10 feet fresh out of peanuts and the next oscillation I knew we were in trouble, extended long and slow very significant difference between approach and landing. The most significant that I've seen. You could not believe that you would have as much trouble as you do under 25 ft.

WIND AND TURBULENCE: Wind and turbulence not a factor. Lat-Dir. not a factor.

SUMMARY COMMENTS: Major problems were precise control of sink rate close to the ground and Lord knows what was happening to the landing gear back there as we were floundering around in the oscillation. I don't feel like I was losing control in a sense of pitch oscillation, but I was certainly losing control of my sink rate so that's what I mean. You don't feel like it's losing control of pitch attitude directly, but clearly got into oscillations when I attempted to enter the loop under 25 ft.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A RATING 9 PIO 5
Short	α_{Hi}	-10	A	4.2	--	.87	18	A	

FLT/CONF.	618/4	WIND	5-10 kt tailwind	VISIBILITY	Clear
DATE	8/4/80	TURB.	Light	AIRPORT	Niagara

FEEL:
- Forces: Medium to a little heavy.
- Displacement: Large.
- Sensitivity: O.K..
- Trim: Didn't trim too much.

PITCH ATTITUDE RESPONSE:
- Initial: Noticeably delayed.
- Predictability:
- Special Inputs:
- PIO Tendency:

Predictability of pitch is not bad IFR and also VFR when you are up and away from the ground but as soon as the ground comes in you really definitely can perceive the altitude errors and it screws you up and starts a PIO going. I think it is an input I'm putting in to correct the altitude errors that causes the PIO.

AIRSPEED CONTROL: Wasn't really bad. Surprisingly.

PERFORMANCE:
- Approach Tasks:
  - ILS: Can't remember too clear. Localizer was good. Airspeed wasn't bad.
  - Visual (Sidestep): Sidestep was easy.
- Landing Tasks: Problems came in the flare and touchdown because of PIO in pitch and it was very, very hard to stabilize the flight path close to the ground. Kind of reminds me of the shuttle.
- Differences:

WIND AND TURBULENCE: Didn't particularly notice turbulence. May have been setting off PIO because I did detect an altitude error that was growing and I didn't seem to be.able to control it. My efforts to control it seemed to drive me into the PIO. Lat-Dir. was O.K..

SUMMARY COMMENTS: Major problem - The PIO in flare and touchdown. As you start tight control in the flare, it causes an oscillation that is divergent.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT	A
Short	α_{Hi}	-10	A	4.2	--	.87	18	A	RATING	8
									PIO	4

FLT/CONF.	630/2	WIND	Headwind	VISIBILITY	Partly cludy & slightly hazy.
DATE	8/13/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Heavy. Steady elevator required in steady turn.
- Displacement: Large.
- Sensitivity: I increased it initially and considered further increase but decided against it. Might increase PIO tendency.
- Trim: I guess I didn't trim, but I sure got airspeed variations.

PITCH ATTITUDE RESPONSE:

- Initial: Very sluggish and delayed.
- Predictability: Poor.
- Special Inputs: Either overdrive it, which tends to result in overcontrol or to just nudge it around, don't overdrive it.
- PIO Tendency: Definite tendency to PIO.

AIRSPEED CONTROL: Poor. Always behind it and trying to correct. The inaccuracy in pitch control is a significant part of problem.

PERFORMANCE:

- Approach Tasks:
  - ILS: Poor until I got steady down then fair. Localizer degraded because of lack of attention. Airspeed was poor. Altitude control extremely difficult.
  - Visual (Sidestep): Sidestep went O.K. laterally but got off in vertical flight path.
- Landing Tasks: Flare and touchdown performance was very variable. If you are right on, it came out fairly decently. But if you're off and try to correct back, it was just hopeless. The pilot-airplane combination for any sizeable correction is very poor dynamically, very slow and very oscillatory.
- Differences: Both approach and landing were difficult. It was the landing that's going to kill you though.

WIND AND TURBULENCE: Turbulence is distracting. Lat-Dir. was good.

SUMMARY COMMENTS: Major problem is the slow, inadequate pitch response, difficulty in predicting what to put in to get what you want. Tend to overdrive it or to shift to a mode where you just kind of nudge it around, in which case you don't have the desired bandwidth in generating airplane responses.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Short	αHi_{DLC}	-10	A	4.2	--	.87	18	A	RATING 6
									PIO 3

FLT/CONF.	630/3	WIND	Headwind	VISIBILITY	Partly cloudy & slightly hazy.
DATE	8/13/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Elevator forces on the heavy side, but not too heavy.
- Displacement: Medium.
- Sensitivity: Little low, but about right. Had to put nose down elevator trim in on final a couple of times. Don't understand that.

PITCH ATTITUDE RESPONSE:

- Initial: Very slow initial response, ponderous.
- Predictability: Poor.
- Special Inputs: Either don't put much in and sit there and wait or try to overdrive it, but not too much.
- PIO Tendency: Definite tendency to PIO in pitch on flight path control close to ground.

AIRSPEED CONTROL: Difficult and high workload, but you can do it.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope and localizer not too bad except got high and fast close in. Airspeed was a problem, high workload.
  - Visual (Sidestep): Sidestep easy but the vertical flight path was difficult to control and tended to get off.
- Landing Tasks: Flare and touchdown - I tried to control attitude. The best combination was to control attitude and do most of the flare with the elevator but not worrying about the tight control of sink rate, then control the sink rate with the DLC. That worked pretty well in the last two landings but I didn't have force feel on my DLC controller. DLC controller is not the best predictor type device, I tended to overdo it, maybe if I had force feel -- I don't really know but anyway it's not optimized. That technique tends to work but it's high workload because you have elevator and aileron to control with your left hand and airspeed plus DLC with the right hand so you're busy.
- Differences: The most difficult to control is the flare and touchdown, but flight path and airspeed on final during turns was also a problem. Lat-Dir. is best part of this configuration.

WIND AND TURBULENCE: Crosswind correction was easy.

Flt/Conf. 630/3 (Cont'd)

SUMMARY COMMENTS: Major problem - High workload but I was able to stay out of trouble with the configuration by using the DLC, whereas, I would have gotten into a significant PIO in trying to flare. I felt slow and ponderous and difficult close to the ground as far as elevator control went. Good features - The DLC gave me a tighter control of the sink rate near touchdown and especially, I want this noted, to be able to start back down if I had overrotated with my elevator in pitch. To be able to start down promptly is a highly desirable feature of the DLC - and then being able to take out that down correction quickly. It's very helpful. It makes it possible to come down a little without rotating, I'd never have gotten it done if I had to rotate the airplane.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Short	α_{Hi}	-10	B	4.2	--	.87	18	A	RATING	10
									PIO	6

FLT/CONF.	619/1	WIND	5-10 kt tailwind	VISIBILITY	Clear
DATE	8/4/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Heavy on first approach, arm got tired. Increased gain by about 1.43 and then forces were moderate.
- Displacement: Large.
- Sensitivity: Too heavy on initial approach. Increase by 1.43.
- Trim: Didn't use trim.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed.
- Predictability: Unpredictable.
- Special Inputs: Not too special IFR.
  VFR you try to perform flare and touchdown you get divergent PIO.
- PIO Tendency:

AIRSPEED CONTROL: Taxing, lots of attention.

PERFORMANCE:

- Approach Tasks:
  - ILS: Not bad at all. Airspeed was little poor.
  - Visual (Sidestep): Sidestep easy.
- Landing Tasks: Flare and touchdown - go into PIO and it was just hopeless. Tried three landings and couldn't do it. Safety pilot took control.
- Differences: Landing is more difficult, it's divergent PIO.

WIND AND TURBULENCE: Turbulence was submerged in other problems. Lat-Dir. only good thing.

SUMMARY COMMENTS: Major problem - PIO in flare and touchdown. It was divergent. I couldn't land it in three attempts. Everything proceeded normally until I got down to about 200 ft and then it fell out of the sky on the flare and I went into a PIO, overrotate, balloon, overrotate down, etc..

SHORT AFT TAIL q AUGMENTATION — PILOT COMMENT SUMMARIES

Med q	—	$T_1 = A$
High q ($X_{PCR} = -10'$)	—	$T_1 = A$, *Shuttle lag/delay*
High q ($X_{PCR} = 10'$)	—	$T_1 = A$
High q	—	$T_1 = A$
Ex-High q	—	$T_1 = A$

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Short	q_{med}	-10	A	4.2	1.0	.87	18	A	RATING	9
									PIO	4

FLT/CONF.	619/3	WIND	5-10 kt tailwind	VISIBILITY	Clear		
DATE	8/4/80	TURB.	Light	AIRPORT	Rochester		

FEEL:

- Forces: Medium
- Displacement: Large
- Sensitivity: Asked that be increased after first approach.
- Trim: Didn't use trim.

PITCH ATTITUDE RESPONSE:

- Initial: Very sluggish and delayed.
- Predictability: Difficult to predict.
- Special Inputs: Stay on top of it all the time. In flare you had to generate a lot of corrective lead type inputs to nurse the response towards what you want.
- PIO Tendency: Very strong PIO tendency but it can be made convergent.

AIRSPEED CONTROL: Poor primarily because I didn't have time to give it much attention.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope was fair. Localizer reasonably good. Airspeed had excursions.
  - Visual (Sidestep): Sidestep easy.
- Landing Tasks: Flare and touchdown was a problem, had a tendency to overrotate. PIO, whenever you wanted to make a correction in flight path. Just don't know what kind of an input to put in.
- Differences: Approach was a lot less difficult than landing.

WIND AND TURBULENCE: It is turbulent today which makes it hard to ever really get set up.
• Lat-Dir good.

SUMMARY COMMENTS: Major problem is pitch PIO in flare and touchdown. Difficult to predict what kind of input to put in to get the flight path response you want.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Short	q_{Hi}	-10	A	4.2	1.0	.87	18	A	RATING 6
									PIO 3

FLT/CONF.	615/5	WIND	Headwind	VISIBILITY	Clear
DATE	7/31/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: No problem.
- Displacement: No problem.
- Sensitivity: O.K.

PITCH ATTITUDE RESPONSE:

- Initial: Pitch response was excellent. Certainly at all times except the very last approach, even then I was able to retain a reasonable control. Initial response was good.
- Predictability: Predictability was good.
- Special Inputs: Not to make inputs near the ground.
- PIO Tendency: If you use the wrong technique. It's related to technique you use.

AIRSPEED CONTROL: Good on first and reasonable on the second.

PERFORMANCE:

- Approach Tasks:
  - ILS: You can do excellent ILS. It's an excellent airplane.
  - Visual (Sidestep): Good visually down to last bit but you got to get organized there. You have to get set up so you come through the window correctly and then almost hands off technique close in. Use the trim to make inputs.
- Landing Tasks: Flare and touchdown was the problem. Performance was both good and bad. It's very much a function of control technique.
- Differences: Difference is significant and landing is clearly the most difficult.

WIND AND TURBULENCE: Wind and turbulence was not a factor. Lat-Dir was not a factor.

SUMMARY COMMENTS: Major problem is precision of height control near the ground. I'd like to see it again, didn't get consistent results.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A RATING 9 PIO 4
Short	q_{Hi}	-10	A	4.2	1.0	.87	18	A	

FLT/CONF.	619/4	WIND	5-10 tailwind	VISIBILITY	Clear
DATE	8/4/80	TURB.	Light	AIRPORT	Rochester

FEEL:

- Forces: Medium or a little heavier. No steady forces in the turn.
- Displacement: Medium or a little larger.
- Sensitivity: About right but the feel is terrible, it just --- you don't feel like you are too connected to the airplane.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed.
- Predictability: Not at all good, but adequate for IFR portion. It's no way near adequate for flare and touchdown.
- Special Inputs: Had not developed one.
- PIO Tendency: Definite tendency to PIO.

AIRSPEED CONTROL: Difficult in the approach. You were so busy in the flare that airspeed control was not existent.

PERFORMANCE:

- Approach Tasks:
  - ILS: Fair but workload was high. Airspeed control was a problem also rate of climb. Localizer didn't seem to correct as well as others. Performance was certainly adequate.
  - Visual (Sidestep): Sidestep was not difficult.
- Landing Tasks: The flare is the problem, especially down close to touchdown. Tended to overrotate. Flight path just doesn't want to go that last 6 inches or one foot. I ended up with the flight path going up and then it's hard to correct, end up with another shot back down on the runway with sink rate that is too large.
- Differences: By far the landing was the most difficult.

WIND AND TURBULENCE: Turbulence was a problem, it knocks you off the glide slope and it's very difficult to get back on. Lat-Dir pretty good.

SUMMARY COMMENTS: Major problems was flare and touchdown. I'm tired having crappy airplanes in the flare and touchdown. If you can't build them any better than this, we better not build them.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Short	q_{Hi}	-10	A	4.2	1.0	.87	18	A	RATING 5
									PIO 3

FLT/CONF.	630/1	WIND	6 kt headwind	VISIBILITY	Partly cloudy & Slightly hazy
DATE	8/13/80	TURB.	Light turbulence	AIRPORT	Niagara

FEEL:

- Forces: Heavy initially, medium after I increased the gearing. No force required for turn.
- Displacement: Large initially, medium after gain increase.
- Sensitivity: Prefer the higher setting.
- Trim: Didn't use trim, didn't have to.

PITCH ATTITUDE RESPONSE:

- Initial: Little delayed and sluggish.
- Predictability: Little hard to predict final but adequate.
- Special Inputs: I was probably overdriving it some.
- PIO Tendency: I hate to call it a PIO but it certainly had some overcontrol tendency in flare and touchdown, which appeared as an oscillation.

AIRSPEED CONTROL: Fair, required attention.

PERFORMANCE:

- Approach Tasks:
  - ILS: Somewhat busy, had airspeed variations. Glide slope attention took some attention off localizer. Airspeed, noticeable workload.
  - Visual (Sidestep): Sidestep was easy. Didn't have much trouble with vertical flight path.
- Landing Tasks: Flare - I was a little behind, but I had control.
- Differences: Approach and landing similar difficulty with a little more trouble with the touchdown.

WIND AND TURBULENCE: Turbulence added to airspeed corrections. Lat-Dir. pleasant but a little heavy.

SUMMARY COMMENTS: No major problems but the airplane is slow, sluggish responding in pitch. But I do have adequate control. Didn't get desired performance in airspeed or flight path control in the flare and touchdown. Tendency to be late in the flare, ponderous and a little hunting for the ground in pitch.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	
Short	q_{Hi}	-10	A	4.2	1.0	.87	18	A	PILOT B RATING 4 PIO 2

FLT/CONF.	631/5	WIND	12 kt headwind	VISIBILITY	Light rain and hazy
DATE	8/14/80	TURB.	Moderate	AIRPORT	Buffalo

FEEL:
- Forces: Reasonable.
- Displacement: Reasonable.
- Sensitivity: Reasonable.

PITCH ATTITUDE RESPONSE:
- Initial: Slow.
- Predictability: No problem.
- Special Inputs: No.
- PIO Tendency: No.

AIRSPEED CONTROL: O.K..

PERFORMANCE:
- Approach Tasks:
  - ILS: Satisfactory.
  - Visual (Sidestep): Satisfactory.
- Landing Tasks: Flare - used more gradual throttle changes and it seemed to work out better. I had more trouble with the directional and lateral correction in that particular landing than anything else. I was unable to really get set up for it. I don't think it's a fair offset for a large airplane - I would have gone around.
- Differences: No significant difference between approach and landing.

WIND AND TURBULENCE: The crosswind seemed larger than usual, I had both hands on the wheel and a lot of rudder, more than I've been used to.

SUMMARY COMMENTS: No major problems. I thought it was a little slow in pitch, a little tendency to be less precise than you want. Had a little tendency to overcontrol in the flare but wasn't set up very good.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Short	$q_{Hi_{DLC}}$	-10	A	4.2	1.0	.87	18	A	RATING	5
									PIO	3 elev. 2 DLC

FLT/CONF.	629/3	WIND	15 kt headwind	VISIBILITY	Partly cloudy
DATE	8/12/80	TURB.	Moderate	AIRPORT	Niagara

(See Detail Comments for DLC experience)

FEEL:
- Forces: Medium
- Displacement: Medium
- Sensitivity: Probably should have tried it a little higher.

PITCH ATTITUDE RESPONSE:
- Initial: Delayed.
- Predictability: Not quite so good with elevator.
- Special Inputs: Overdrive a little maybe.
- PIO Tendency: None on glide slope but some in the flare and touchdown with elevator.

AIRSPEED CONTROL: Requires a lot of thrust in turns.

PERFORMANCE:
- Approach Tasks:
  - ILS: Fairly good. Didn't use DLC in approach.
  - Visual (Sidestep): Sidestep easily done in roll but some tendency to lose the flight path in vertical.
- Landing Tasks: Flare - If done with the elevator, the response is delayed and some tendency to oscillate, tendency to overrotate. Touchdown performance, only did one with elevator and that one wasn't too bad.
- Differences: The landing is more difficult than the approach. Flare and touchdown with the DLC, it is only used on flight path but it is difficult to know how much change in h that you are commanding. I just moved the thumb control and see what happens. After a few landings, I was doing it about right.

WIND AND TURBULENCE: Crosswind corrections were O.K.. Some tendency to neglect the crosswind when using DLC.

SUMMARY COMMENTS: Major problem is four controls, I was learning and it is probably a help but I'm not sure that's the kind of help I want. Workload is high with four controllers. I'm still learning to use DLC and the controller isn't optimized. Sense of control was O.K., never used it backwards.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Short	q_{Hi}	+10	A	4.2	1.0	.87	18	A	RATING 5 PIO 1

FLT/CONF.	629/1	WIND	260° @ 15 kt	VISIBILITY	Partly cloudy
DATE	8/12/80	TURB.	Moderate	AIRPORT	Buffalo

FEEL:

- Forces: Medium
- Displacement: Small to medium
- Sensitivity: Liked the value I had.
- Trim: Didn't have to trim.

PITCH ATTITUDE RESPONSE:

- Initial: Delayed a little but didn't seem to give me any significant problem in the flare and touch n.
- Predictability: Seemed predictable. I didn't overrotate.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Principal problem was airspeed control. Wasn't bad when I was wings level constant speed flight but if I would be turning or rolling out of the turn or in response, it had a tendency to get slow or fast. Sluggish thrust response.

PERFORMANCE:

- Approach Tasks:
  - ILS: Quite good ILS and localizer. Turning, I had little trouble with airspeed.
  - Visual (Sidestep): Easy to correct and no problem with vertical flight path during the maneuver.
- Landing Tasks: I landed a little early and hard on first two but I think the problem is primarily getting used to Buffalo airport and the radar altitude for this runway. (Sharp change in elevation near threshold). Third landing, the sink rate was kept small without overrotation. No special technique, except watch airspeed.
- Differences: Approach was more difficult because of airspeed control.

WIND AND TURBULENCE: Not sure what the effect of turbulence was. Crosswind easy. Lat-Dir was good.

SUMMARY COMMENTS: Principal problem was airspeed control, did not get desired performance. Good features - Lat-Dir and in a sense the pitch control and the flare and touchdown wasn't bad.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Short	q_{Hi}	10	A	4.2	1.0	.87	18	A	RATING 8 land. PIO 4 appr. 3 flare

FLT/CONF.	631/1	WIND	SW @ 12 kt	VISIBILITY	Light rain and slightly hazy
DATE	8/14/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: No complaints.
- Displacement: No complaints.
- Sensitivity: Satisfactory.
- Trim: I really didn't like the airplane even in the approach. It didn't seem to trim in an attitude and hold it, I had to be trimming all the time. Wasn't a solid airplane on approach.

PITCH ATTITUDE RESPONSE:

- Initial: Little bit delayed. I didn't have a great deal of difficulty, didn't feel smooth, a little lumpy.
- Predictability:
- Special Inputs:
- PIO Tendency: No tendency toward a PIO except right near the end. Tend not to want to touch it, lack of controllability you would like to see in the flare.

AIRSPEED CONTROL: Reasonable, required work but could get job done.

PERFORMANCE:

- Approach Tasks:
  - ILS: No problem on ILS, throttles are used open loop, you move the throttle and wait an hour until it settles down.
  - Visual (Sidestep): No difference from IFR.
- Landing Tasks:
- Differences: The real differences is in flare and touchdown. The problems are an inability to fly in a natural fashion and be precise with a touchdown point without feeling that you are going to overcontrol and hit the ground too hard and fall out the bottom like I did on the second one. The clear problem is the landing, it's significant right near the end. Lot of mental workload to keep from overcontrolling and getting into a balloon situation in touchdown. You can hit the ground pretty hard in this airplane.

WIND AND TURBULENCE: Wind and turbulence not really a factor. Crosswind no problem. Lat-Dir. not a factor.

SUMMARY COMMENTS: Major problem is the last 30-40 ft in the landing. I just have a feeling that I am not totally in control of the rate of sink at touchdown, or the touchdown point. Worry about hitting ground too hard. Second landing contributes to this fear. On approach it is something like a 4.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Short	q_{Hi}	50	A	4.2	1.0	.87	18	A	RATING	4-1/2
									PIO	1

FLT/CONF.	629/2	WIND	260^{o} @ 15 kt	VISIBILITY	Partly cloudy
DATE	8/10/80	TURB.	Moderate	AIRPORT	Buffalo

FEEL:
- Forces: Medium and comfortable.
- Displacement: Medium to small.
- Sensitivity: Didn't do any trimming.

PITCH ATTITUDE RESPONSE:
- Initial: Prompt for a big airplane.
- Predictability: Pretty predictable.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Bit of a problem.

PERFORMANCE:
- Approach Tasks:
  - ILS: Very good. Airspeed on ILS was fair.
  - Visual (Sidestep): Sidestep was easy.
- Landing Tasks: No particular problem in flare.
- Differences: Approach was more difficult, I had to watch the airspeed a lot and had problems with speed in the flare.

WIND AND TURBULENCE: Crosswind corrections were easy, took turbulence in stride. Lat-Dir were good.

SUMMARY COMMENTS: Major problem was airspeed control and thrust lag. Don't know where to put the throttle to get the trim thrust back. Have to look at throttle and guess where to put it. Didn't get desired performance in airspeed. On last approach turning final, I let the airspeed get down to 142 kt and with full power on, nothing much happened, gradually started to pick up.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Short	q_{Hi}	50	A	4.2	1.0	.87	18	A	RATING 3
									PIO 1

FLT/CONF.	631/4	WIND	SW @ 12 kt	VISIBILITY	Light rain and slightly hazy.
DATE	8/14/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:

- Forces: No problem.
- Displacement: No problem.
- Sensitivity: Satisfactory.

PITCH ATTITUDE RESPONSE:

- Initial: Good.
- Predictability: Predictable.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL:

PERFORMANCE:

- Approach Tasks:
  - ILS: Didn't achieve the performance on first two approaches that I expected. There was some confusion of the first couple. Concentrated a little more on third one and you can do the job.
  - Visual (Sidestep): Can do.
- Landing Tasks: Felt I had reasonable control of sink rate and touchdown point.
- Differences: No real difference between approach and landing. Final flare was a little more difficult.

WIND AND TURBULENCE: Felt turbulence in ride quality sense, not in terms of control problem. Crosswind correction required seemed to change as got closer to ground, maybe variable wind.

SUMMARY COMMENTS: No major problems. Good features - sense of control near the ground, I could control the sink rate in satisfactory manner. I must admit that knowing the kind of airplane (short tail) that I'm flying and of course not knowing what on earth is going on with them - there is a tendency to want to say, well, I should be having more difficulty --- a reluctance to give full marks for precision.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Short	q_{Hi}	-10	Shuttle lag/delay	4.2	1.0	.87	18	A	RATING 9
									PIO 5

FLT/CONF.	631/2	WIND	SW @ 12 kt	VISIBILITY	Light rain and slightly hazy
DATE	8/14/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: O.K..
- Displacement: O.K..
- Sensitivity: Satisfactory.
- Trim: Has PIO tendency if you hand fly it at any time on an accurate attitude. You can fly with the trim most of the approach, but near the end if you are trying to make a correction, it's very difficult to avoid a PIO.

PITCH ATTITUDE RESPONSE:

- Initial: Big initial delay.
- Predictability: Poor.
- Special Inputs: Use trim as much as possible; not make any inputs.
- PIO Tendency: PIO anytime you try to be accurate with the airplane.

AIRSPEED CONTROL: Reasonable.

PERFORMANCE.

- Approach Tasks:
  - ILS: Using trim, could achieve adequate ILS.
  - Visual (Sidestep): Sidestep can be done, rather not have to though. You would like to be stabilized far out on final and not have to touch anything.
- Landing Tasks: Flare and touchdown is clear problem area. Special technique is to try to stay out of loop. It's a very tense airplane to fly near the end because you're worried that you are going to touch it at the wrong time and get into an oscillation.
- Differences: Tendency to PIO and landing is most difficult.

WIND AND TURBULENCE: Wind and turbulence no problem. Lat-Dir. not a factor.

SUMMARY COMMENTS: Major problem - lack of predictability in the pitch response combined with a difficult airplane to feel a sense of control of sink rate near the end of the flare. Can't consistently land it with acceptable sink rate. Inability to make corrections in the flare.

Note:

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Short	q_{ExHi}	-10	A	4.2	0.5	.87	18	A	RATING 4
									PIO 2

FLT/CONF.	631/3	WIND	SW @ 12 kt	VISIBILITY	Light rain and slightly hazy.
DATE	8/14/80	TURB.	Moderate	AIRPORT	Niagara

FEEL:
- Forces: No complaints.
- Displacement: No complaints.
- Sensitivity: Satisfactory.
- Trim: Decent airplane to trim.

PITCH ATTITUDE RESPONSE:
- Initial: O.K..
- Predictability: Good.
- Special Inputs: Could fly the airplane and not feel apprehension and muscle tightening worry about getting into trouble.
- PIO Tendency: None.

AIRSPEED CONTROL: What you want to make it. Satisfactory. I found I was actually relaxing in this airplane compared to some. In relaxing you tend to get a little sloppy.

PERFORMANCE:
- Approach Tasks:
  - ILS: No problem.
  - Visual (Sidestep): No problem.
- Landing Tasks: I may be learning to fly these things. I seem to have a lot more confidence with this airplane that I could put it down where I wanted it. Felt like I had to work just a little bit at the end, a little sense of caution, but I kept things under control.
- Differences: Landing clearly more difficult than approach.

WIND AND TURBULENCE: Didn't notice turbulence problems, but crosswind seemed stronger than before. The correction takes time, it's slow coming around. Have to get organized as you would in a big airplane, allow a reasonable distance, you can get it done.

SUMMARY COMMENTS: Major problem - none. I felt a sense of relief being able to fly the airplane close to the ground without PIO. I felt a little apprehension at the end and a little work. I feel comfortable with this airplane but I don't feel like I'm achieving the performance that I expect.

LATERAL-DIRECTIONAL PILOT COMMENT SUMMARIES

Note: Longitudinal pilot comments were also given with these evaluations which were devoted to the lateral-directional axes. The longitudinal configuration flown with all of these evaluations was the Long Aft Tail with High q-feedback, $T_1 = A$. The longitudinal pilot comment summaries are also presented.

$\tau_R = .87$, $Z_{sp} = -18'$ $T_1 = A, B, C$
$\tau_R = .44$, $Z_{sp} = -18'$ $T_1 = A, B, C$
$\tau_R = .87$, $Z_{sp} = -36'$ $T_1 = A$
$\tau_R = .44$, $Z_{sp} = -36'$ $T_1 = A$

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	(	92.5	A	4.2	1.0	.87	18	A	RATING	4-1/2
									PIO	2

FLT/CONF.	623/4	WIND	8 kt from right	VISIBILITY	Clear
DATE	8/6/80	TURB.	Light and moderate	AIRPORT	Rochester

FEEL:
- Forces: Medium to small forces and displacements.
- Displacement:
- Sensitivity: O.K. wouldn't have changed. Trim, didn't have to trim particularly.

PITCH ATTITUDE RESPONSE:
- Initial: Appears same as has been. Not a problem until I get those low frequency heaves that prevent me touching down or cause sink.
- Predictability:
- Special Inputs:
- PIO Tendency: Heave problem.

AIRSPEED CONTROL: Adequate.

PERFORMANCE:
- Approach Tasks:
  - ILS: Fairly good. Glide slope and localizer went reasonably well.
  - Visual (Sidestep): It was in the sidestep where I noticed heavy forces or low response in roll. Biggest problem was lineup correction.
- Landing Tasks: Had heck of a time in pitch on one landing. Sank just like I hit a down draft at about 200 ft. Got double red on VASI. Added power, started correcting back and suddenly got same thing in opposite direction, big heave. Try to ignore this,don't think this is representative of configuration.
- Differences:

WIND AND TURBULENCE: Not a particular factor except in those sinks and heaves.

SUMMARY COMMENTS: Rated a 4 then changed to 4-1/2 because of low rol' response.

Flt/Conf. 623/4

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	
Authority	Roll forces seem heavy. Displacements are large
Sensitivity	Authority appeared to be low. Roll sensitivity was low.
Response	Response delay in roll. Not enough response to roll inputs.
Overshoot Tendency	No tendency to overshoot.
HEADING RESPONSE	
Turn Entry	Adequate.
Rollout of turn	Some tendency to overshoot rollouts because of low roll response rate.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	Sideslip stayed centered in all rolling maneuvers.
RUDDER CONTROL	
Authority	Low but adequate.
Sensitivity	Insensitive.
TENDENCY TO HOLD BANK	Good tendency to hold bank angle.
ROLL-PITCH CONTROL HARMONY	Feels heavier in roll and lighter in pitch but not out of limits.
RIDE QUALITY	
Lateral Accel.	Fine. No significant side acceleration due to roll control.
Turbulence	Not unusual.
Input Magnitude causing objectional lateral accel.	
MAJOR PROBLEMS	Low roll control authority, worried about final part of lineup.
GOOD FEATURES	

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Long	q_{Hi}	92.5	A	4.2	1.0	.87	18	B	RATING 4-1/2
									PIO 3

FLT/CONF.	624/1	WIND	10 kt headwind	VISIBILITY	Partial overcast
DATE	8/8/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Forces feel relatively light. No elevator required in steady turn.
- Displacement: Small in pitch.
- Sensitivity: Good, didn't have to trim very much.

PITCH ATTITUDE RESPONSE:

- Initial: Slow but know it's coming.
- Predictability: of final response is pretty good.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Somewhat a problem get fast and slow, thrust response is too long. Makes me keep looking at thrust. It takes attention, leads to inaccuracies.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope and localizer good.
  - Visual (Sidestep): Sidestep c [illegible]ction was relatively easy to make although the airplane felt heavy and ponderous.
- Landing Tasks: Flare and touchdown in pitch went very well. Roll wasn't really bad but felt heaviness and delay in last minute lateral touchdown corrections.
- Differences: Visual part was more difficult because I attempted to maneuver more rapidly.

WIND AND TURBULENCE: Turbulence acted as exciter particularly in roll. Tired left arm.

SUMMARY COMMENTS:

Flt/Conf. 624/1

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	
Authority	Roll forces feel on heavy side, displacements feel large. Authority a little low.
Sensitivity	Sensitivity felt low.
Response	Delay in initial roll response.
Overshoot Tendency	Feels like a very big airplane. Sluggish to get going, tends to continue to roll after input neutralized. Seemed rolly in bank angle control, especially as I get tighter on the localizer. Seemed to be always working in bank angle. A little overshoot after I neutralize ailerons.
HEADING RESPONSE	Required attention for corrections.
Turn Entry	Turn entries and normal rates it's great.
Rollout of turn	Normal rollouts it feels a little heavy. Don't have any tendency to overshoot heading.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	No sideslip induced by rolling and that certainly is great.
RUDDER CONTROL	Sluggish and heavy but adequate.
Authority	
Sensitivity	
TENDENCY TO HOLD BANK	Poorer than most but acceptable, adequate.
ROLL-PITCH CONTROL HARMONY	Out of kilter, roll is heavier.
RIDE QUALITY	
Lateral Accel.	No significant lateral acceleration.
Turbulence	
Input Magnitude causing objectional lateral accel.	
MAJOR PROBLEMS	Roll control is only significant objection.
GOOD FEATURES	Lack of sideslip in rolling and turning maneuvers.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT	A
Long	q_{Hi}	92.5	A	4.2	1.0	.87	18	C	RATING	5
									PIO	2

FLT/CONF.	626/1	WIND	5-10 kt tailwind	VISIBILITY	Overcast but app's in clear air.
DATE	8/11/80	TURB.	Light	AIRPORT	Niagara

FEEL:
- Forces: Medium.
- Displacements: Medium to small.
- Sensitivity: Just right, don't have to trim.

PITCH ATTITUDE RESPONSE:
- Initial: Ponderous but it is predictable.
- Predictability:
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Fair, don't have much cue when you get off airspeed. Must monitor attitude and power settings.

PERFORMANCE:
- Approach Tasks:
  - ILS: Glide slope and localizer were good. Localizer was higher workload, in close.
  - Visual (Sidestep): Felt a bit rolly and required bigger aileron inputs. Sidestep, felt heavy and behind you.
- Landing Tasks: Fairly accurate control of touchdown. Bank control is little heavy and inaccurate when in close making tight corrections.
- Differences: Visual more difficult, lineup and sidestep.

WIND AND TURBULENCE: Stimulates the airplane to be rolly.

SUMMARY COMMENTS: Little bit rolly, little bit heavy in roll. Have to put corrections in back and forth.

Flt/Conf. 625/1

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL Authority Sensitivity Response Overshoot Tendency	It's definitely heavy in roll and a little slow, noticeably slow in responding in roll. Kind of funny feeling. I put in an input and I don't feel much for a little bit and then it starts to roll and when it starts to roll it comes off promptly but of course I have a lot of aileron an by then. You are starting to get behind the airplane in bank angle control. That's the major objection. It's mostly just a big delay in the response and I'm overdriving it and it makes it feel heavy and sluggish.
HEADING RESPONSE Turn Entry Rollout of turn	Not a problem.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	No sideslip irduced by roll control.
RUDDER CONTROL Authority Sensitivity	Heavy,ponderous but adequate.
TENDENCY TO HOLD BANK	Maintains bank fairly well except in turbulence and then it's rolly.
ROLL-PITCH CONTROL HARMONY	Little heavy in roll.
RIDE QUALITY Lateral Accel. Turbulence Input Magnitude causing objectional lateral accel.	No problem.
MAJOR PROBLEMS	Behind airplane in roll. Low roll authority, the dynamic authority.
GOOD FEATURES	No sideslip induced by roll control.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Long	q_{Hi}	92.5	A	4.2	1.0	.44	18	A	RATING 3 PIO 2

FLT/CONF.	623/2	WIND	8 kt from right	VISIBILITY	Clear
DATE	8/6/80	TURB.	Light to moderate	AIRPORT	Rochester

FEEL:
- Forces: Medium
- Displacement: Medium to small for big airplane.
- Sensitivity: Seemed right.
- Trim: Didn't have to trim much.

PITCH ATTITUDE RESPONSE:
- Initial: Reasonably prompt for big, slow, sluggish airplane.
- Predictability: Reasonably predictable.
- Special Inputs: --
- PIO Tendency: None, some tendency to balloon.

AIRSPEED CONTROL: Reasonable.

PERFORMANCE:
- Approach Tasks:
  - ILS: Excellent glide slope, localizer, airspeed.
  - Visual (Sidestep): Sidestep easy to perform.
- Landing Tasks: Two out of three flare and touchdown good but high workload. Second approach had balloon problem and landed long.
- Differences: Landing more difficult at least in pitch.

WIND AND TURBULENCE: Turbulence didn't effect too much. Runway heat may have caused balloon on second one.

SUMMARY COMMENTS: Lateral-directional characteristics were very good. Some problem with balloon tendency in flare.

Flt/Conf. 623/2

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	Good
Authority	Good
Sensitivity	Good
Response	Prompt and good
Overshoot Tendency	None
HEADING RESPONSE	
Turn Entry	Good
Rollout of turn	Predictable
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	No tendency to sideslip.
RUDDER CONTROL	Heavy and slow but adequate.
Authority	
Sensitivity	
TENDENCY TO HOLD BANK	Good bank angle control.
ROLL-PITCH CONTROL HARMONY	Good
RIDE QUALITY	Good
Lateral Accel.	
Turbulence	
Input Magnitude causing objectional lateral accel.	
MAJOR PROBLEMS	No major problems. Balloon tendency.
GOOD FEATURES	Roll characteristics. Prompt initially.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Long	q_{Hi}	92.5	A	4.2	1.0	.44	18	A	RATING 2
									PIO 1

FLT/CONF.	625/2	WIND	Headwind	VISIBILITY	Very hazy
DATE	8/8/80	TURB.	Moderate	AIRPORT	Niagara & Buffalo

FEEL:

- Forces: O.K.
- Displacement: O.K.
- Sensitivity: O.K.

It flew like a big airplane. You could manage it with big airplane-like task requirements in a very smooth fashion.

PITCH ATTITUDE RESPONSE:

- Initial: Good.
- Predictability: Good.
- Special Inputs: It didn't hold trim perfectly. A little bit of longitudinal stick force occasionally have to retrim.
- PIO Tendency: None.

AIRSPEED CONTROL: As you wanted to make it. Throttles are one step at a time job. Not really part of the closed-loop task.

PERFORMANCE:

- Approach Tasks:
  - ILS: Good.
  - Visual (Sidestep):
- Landing Tasks: Flare and touchdown - I felt like I was driving a big airplane. It felt like you could control it. In fact you get a little lazy with this airplane. You feel like you have that much control.
- Differences: No difference.

WIND AND TURBULENCE: No wind problems. Turbulence required normal effort. Could hear system surging at about 500 ft. Not a detracting factor.

SUMMARY COMMENTS: Good airplane. Feels very smooth, especially in roll. No jerkiness or interactive forces.

Flt/Conf. 625/2

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	
Authority	Good
Sensitivity	Good
Response	Good
Overshoot Tendency	None
HEADING RESPONSE	
Turn Entry	Smooth
Rollout of turn	Good
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	None
RUDDER CONTROL	
Authority	Didn't exercise.
Sensitivity	
TENDENCY TO HOLD BANK	No problem to fly.
ROLL-PITCH CONTROL HARMONY	Good
RIDE QUALITY	O.K.
Lateral Accel.	No unruly accelerations. Some high frequency bumps but nothing to contend with.
Turbulence	Had a little turbulence.
Input Magnitude causing objectional lateral accel.	No problem.
MAJOR PROBLEMS	None
GOOD FEATURES	Good airplane.

TAIL	AUG.	$X_{P_{C.R.}}$	$\tau_1 \sim q$	n/α	q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A
Long	q_{Hi}	92.5	A	4.2	1.0	.44	18	B	RATING 4
									PIO 1

FLT/CONF.	626/2	WIND	5-10 kt tailwind	VISIBILITY	Overcast but app's in clear air.
DATE	8/11/80	TURB.	Light	AIRPOPT	Niagara

FEEL:

- Forces: Medium
- Displacement: Relatively small.
- Sensitivity: About right.
- Trim: Didn't have to trim.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response -- it's there. Slow.
- Predictability: Little unpredictable, especially if you overrotate.
- Special Inputs: None
- PIO Tendency: None

AIRSPEED CONTROL: Fair to good but high workload.

PERFORMANCE:

- Approach Tasks:
  - ILS: Quite good on glide slope and localizer.
  - Visual (Sidestep): Sidestep - you can perform it. You feel lateral acceleration. You don't feel behind the airplane.
- Landing Tasks: Noticed delay in lineup correction initial response. Significant delay in roll response. Touchdown performance was fair. Was concentrating on lateral characteristics. Just shows these pitch characteristics are not all that wonderful.
- Differences: About equally difficult.

WIND AND TURBULENCE: Not significant factor.

SUMMARY COMMENTS: Acceleration environment noticeable but not degrading. Had feeling the acceleration environment helped to know I was getting roll response.

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	
Authority	Seemed enough.
Sensitivity	Pretty good.
Response Overshoot Tendency	Noticed delay in initial response when making lineup correction. Got noticeable lateral acceleration in cockpit which was a little objectionable or bothersome in turbulence and quick maneuvering. No tendency to overshoot in bank angle.
HEADING RESPONSE	
Turn Entry	Good.
Rollout of turn	Good.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	None.
RUDDER CONTROL	
Authority Sensitivity	As usual, heavy and sluggish but adequate. Wouldn't want it significantly different with this low stiffness Dutch roll.
TENDENCY TO HOLD BANK	Fairly good.
ROLL-PITCH CONTROL HARMONY	Fairly good.
RIDE QUALITY Lateral Accel.	Acceleration environment does bother you a little bit. Ride quality degraded by lateral acceleration during sharp rolling maneuvers but otherwise it is pretty good.
Turbulence	
Input Magnitude causing objectional lateral accel.	
MAJOR PROBLEMS GOOD FEATURES	Somewhat objectionable due to lateral acceleration. May have influenced pitch performance. Pilot rating of 4 was given but could almost give it a 3. But not that happy with performance.

TAIL	CG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A RATING 3 PIO 2
Long	q_{Hi}	92.5	A	4.2	1.0	.44	18	C	

FLT/CONF.	624/2	WIND	10 kt headwind	VISIBILITY	Partial overcast
DATE	8/8/80	TURB.	Light	AIRPORT	Niagara

FEEL:

- Forces: Medium to light, no steady force in steady turn.
- Displacement: Small to medium.
- Sensitivity: Just right.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response time is a little long. Big airplane-like.
- Predictability: Reasonably predictable.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Fairly good. Same as usual, requires attention.

PERFORMANCE:

- Approach Tasks:
  - ILS: Good ILS and localizer. Airspeed fair.
  - Visual (Sidestep): Ability to perform sidestep was pretty good. I didn't feel behind the airplane. I felt reasonably comfortable. I had enough roll control authority.
- Landing Tasks: Not bad in flare for a big airplane. Overrotated the last landing just a little bit but corrected. Lateral touchdown position I could control pretty well.
- Differences: Equal difficulty.

WIND AND TURBULENCE: Caused lateral acceleration to be noticeable during sharp corrections.

SUMMARY COMMENTS: Notes side acceleration for abrupt aileron inputs. Notes some delay in initial roll response and tendency to oscillate in roll during tight control near ground. Borderline for 3 rating.

Flt/Conf. 624/2

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	Aileron forces are comfortable and pleasant.
Authority	Adequate and basically pretty good.
Sensitivity	Medium. A little bit of initial response delay which made it feel a little insensitive.
Response	Quick decay in roll rate when you neutralize controls.
Overshoot Tendency	For real tight part close to ground, slight tendency to couple or overshoot a time or two, but I don't fault it for that.
HEADING RESPONSE	
Turn Entry	Good.
Rollout of turn	Easy to roll out on heading, when you neutralize the ailerons the roll rate went to a screeching halt.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	Noen. No induced sideslip at all.
RUDDER CONTROL	Sluggish as usual. Heavy.
Authority	
Sensitivity	Low sensitivity.
TENDENCY TO HOLD BANK	Very good to maintain bank angle.
ROLL-PITCH CONTROL HARMONY	Pretty good.
RIDE QUALITY	
Lateral Accel.	Degraded by the side acceleration but didn't really bother me.
Turbulence	
Input Magnitude causing objectional lateral accel.	Don't understand this question so I haven't been answering it. I could make pretty large inputs, of course side accelerations got larger but it was more the sharpness of the inputs that cause a little unpleasant feeling.
MAJOR PROBLEMS	Side acceleration a little unpleasant. Little bit of control oscillation close to the ground.
GOOD FEATURES	Good thing I could relax on the approach.

TAIL	AUG.	$X_{p_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
									RATING	3
Long	q_{Hi}	92.5	A	4.2	1.0	.44	18	C	PIO	

FLT/CONF.	627/5	WIND	7 kt tailwind	VISIBILITY	Very hazy
DATE	8/11/80	TURB.	Light to moderate	AIRPORT	Niagara

FEEL:

- Forces: Medium
- Displacement: Medium to small
- Sensitivity: Seemed right.
- Trim: Didn't have to trim in pitch.

PITCH ATTITUDE RESPONSE:

- Initial: Noticeable and reasonably prompt.
- Predictability: Fairly good.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Fair, requires attention but it wasn't one of the more difficult ones.

PERFORMANCE:

- Approach Tasks:
  - ILS: Glide slope and localizer very good. Airspeed, tendency to get fast on the approach. Had to keep bringing back power as I descended. That could be a windshear problem.
  - Visual (Sidestep): Sidestep was easily performed.
- Landing Tasks: Went predictably well. Crosswind was easy. No special control techniques.
- Differences: Not significant. Felt side acceleration a little more in lineup correction than in approach.

WIND AND TURBULENCE: Not significant.

SUMMARY COMMENTS:

Flt/Conf. 627/5

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	
Authority	Adequate.
Sensitivity	As high as I want.
Response	Noticeable acceleration at cockpit. Quick roll input causes noticeable side acceleration which was noticeably delayed after the aileron input. So what I felt was aileron input, then a side acceleration coming in and I could cycle back and forth and feel a little bit of coupling but never really noticed it in maneuvering in the task. No roll overshoot tendency.
Overshoot Tendency	
HEADING RESPONSE	
Turn Entry	
Rollout of turn	Heading good.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	None.
RUDDER CONTROL	As usual, heavy, insensitive.
Authority	
Sensitivity	
TENDENCY TO HOLD BANK	Good.
ROLL-PITCH CONTROL HARMONY	Good.
RIDE QUALITY	See above.
Lateral Accel.	
Turbulence	
Input Magnitude causing objectional lateral accel.	
MAJOR PROBLEMS	None - some criticism of side accelerations. Not a real significant factor though.
GOOD FEATURES	Pitch characteristics compared to most of them. Bank angle control wasn't a problem.

TAIL	AUG.	$X_{p_{C.R.}}$	$\tau_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT A RATING 4 PIO 2
Long	q_{Hi}	92.5	A	4.2	1.0	.87	36	A	

FLT/CONF.	623/1	WIND	8 kt from right	VISIBILITY	Clear
DATE	8/6/80	TURB.	Light to moderate	AIRPORT	Rochester

FEEL:

- Forces: Medium for heavy airplane.
- Displacement: Moderate.
- Sensitivity: Seemed about right. Lightened it up a little. Don't have to hold steady elevator in turn.
- Trim: Trim not a factor.

PITCH ATTITUDE RESPONSE:

- Initial: Initial response reasonably quick for a slow airplane.
- Predictability: Pretty predictable except in one flare and touchdown.
- Special Inputs: None.
- PIO Tendency: None.

AIRSPEED CONTROL: Fair. Never very good. Occasionally a little bothersome.

PERFORMANCE:

- Approach Tasks:
  ILS: Glide slope and localizer performance was fine. Airspeed performance was acceptable.
  Vsiual (Sidestep): Lateral acceleration bothersome. Crosswind correction and lineup O.K..
- Landing Tasks: No problem except on one in pitch.
- Differences: Landing more difficult than approach.

WIND AND TURBULENCE: Turbulent in close to ground. Crosswind correction was easy to perform.

SUMMARY COMMENTS: Pitch characteristics fairly good. Overrotation and little difficulty getting down on one landing.

Flt/Conf. 623/1

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	
Authority	Adequate.
Sensitivity	Good for big airplane.
Response	Good.
Overshoot Tendency	No tendency to overshoot in roll.
HEADING RESPONSE	Good.
Turn Entry	
Rollout of turn	Could roll out where I wanted.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	No sideslip in rolling maneuvers.
RUDDER CONTROL Authority Sensitivity	Relatively low power but adequate for a big airplane. Response time in sideslip to rudder is long but acceptable.
TENDENCY TO HOLD BANK	Excellent in maintaining bank angle.
ROLL-PITCH CONTROL HARMONY	Good.
RIDE QUALITY	
Lateral Accel.	Degraded by initial lateral acceleration for roll input. Left roll results in being thrown to right. Confusion factor, especially in close in turbulence.
Turbulence	Turbulence was noticeable, fair amount today.
Input Magnitude causing objectional lateral accel.	Large lateral acceleration when put in significant rolling input. Don't couple with it but might if it were bigger.
MAJOR PROBLEMS	Characterized by large lateral accelerations for quick roll control inputs. Not a major problem but significant.
GOOD FEATURES	Roll inputs don't cause sideslip. Highly desirable.

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{\delta p}$	$\tau_1 \sim p$	PILOT B
Long	q_{Hi}	92.5	A	4.2	1.0	.87	36	A	RATING 4
									PIO 1

FLT/CONF.	625/1	WIND	10 kt headwind	VISIBILITY	Very hazy
DATE	8/8/80	TURB.	Moderate	AIRPORT	Niagara

1 ILS, 2 VFR

FEEL:
- Forces: Longitudinal forces O.K..
- Displacement: O.K..
- Sensitivity: O.K..

PITCH ATTITUDE RESPONSE:
- Initial: O.K..
- Predictability: Very controllable longitudinally, positive control all times.
- Special Inputs: None.
- PIO Tendency: No tendency.

AIRSPEED CONTROL: Good, but got slow on last approach.

PERFORMANCE:
- Approach Tasks:
  - ILS: Good as you want to make it.
  - Visual (Sidestep): No problem.
- Landing Tasks: Satisfactory.
- Differences: No real differences.

WIND AND TURBULENCE: Turbulence noticeable in ride quality. No special control loops required. Crosswind could be handled O.K.. Landed pretty much straight.

SUMMARY COMMENTS: Jerky laterally. Lot of side acceleration in cockpit for abrupt inputs. Typically you don't make abrupt inputs so it is only minor problem.

Flt/Conf. 625/1

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	
Authority	Good.
Sensitivity	Good, no complaints.
Response	O.K..
Overshoot Tendency	No overshoot tendency.
HEADING RESPONSE	
Turn Entry Rollout of turn	Depends on abruptness of inputs. For abrupt inputs side loads at seat are extreme and noticeable. However, for normal context of approach and flying relatively smoothly, it wasn't a big factor, occasional annoyance.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	Have ball excursions but no seat of the pants desire to do anything. So turn coordination not a particular problem.
RUDDER CONTROL	
Authority	Good in contending with crosswind.
Sensitivity	
TENDENCY TO HOLD BANK	Could maintain bank angle.
ROLL-PITCH CONTROL HARMONY	Satisfactory.
RIDE QUALITY	
Lateral Accel. Turbulence Input Magnitude causing objectional lateral accel.	Notice lateral acceleration in the cockpit and turbulence ride problems. Magnitude of input and abruptness. For normal inputs, the accelerations were not unsatisfactory, obviously when you put the step in or when I bashed the control I could feel lateral accelerations but that was not part of the task.
MAJOR PROBLEMS	None, some minor lateral accelerations at cockpit.
GOOD FEATURES	

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT	A
Long	q_{Hi}	92.5	A	4.2	1.0	.44	36	A	RATING	5
									PIO	3

FLT/CONF.	623/3	WIND	8 kt from right	VISIBILITY	Clear
DATE	8/6/80	TURB.	Light to moderate	AIRPORT	Rochester

FEEL:
- Forces: Medium
- Displacement: Small
- Sensitivity: Desirable

PITCH ATTITUDE RESPONSE:
- Initial: It's not a good pitch attitude response in the flare and touchdown.
- Predictability:
- Special Inputs:
- PIO Tendency:

AIRSPEED CONTROL: Fair

PERFORMANCE:
- Approach Tasks:
  - ILS: ILS and localizer good performance.
  - Visual (Sidestep): Side acceleration environment in cockpit somewhat disorienting when I put in roll control inputs. Had to do sidestep very slowly. Had to use small inputs to prevent dumping system.
- Landing Tasks:
- Differences: Approach is as difficult as the landing because it's kind of disorienting on IFR when you get those side accelerations.

WIND AND TURBULENCE: Not too bad.

SUMMARY COMMENTS: System dumps limited the roll maneuvering that could be done. I've cranked my gain down and smoothed my aileron inputs to prevent dumping. Limited evaluation. (Side force surface trips).

Flt/Conf. 623/3

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	
Authority	Would be fine if didn't trip the system.
Sensitivity Response Overshoot Tendency	Fine, except it feels more sensitive, more crisp because of the side acceleration. It feels a little too sensitive. Roll response is O.K. No tendency to overshoot significantly. The lurch sideways is bothersome for turn entry and rollout.
HEADING RESPONSE	
Turn Entry Rollout of turn	Heading response is O.K.. When you try to roll into and out of turns quickly, you feel this big side acceleration.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	No sideslip in rolling maneuvers.
RUDDER CONTROL	
Authority	Heavy and insensitive but adequate.
Sensitivity	
TENDENCY TO HOLD BANK	Adequate
ROLL-PITCH CONTROL HARMONY	O.K.
RIDE QUALITY	
Lateral Accel.	Poor ride. Initial accelerations are high when you roll, objectionable.
Turbulence	
Input Magnitude causing objectional lateral accel.	
MAJOR PROBLEMS	Lateral acceleration and some tendency to couple with aileron inputs. Disorienting.
GOOD FEATURES	

TAIL	AUG.	$X_{P_{C.R.}}$	$t_1 \sim q$	n/α	T_q	τ_R	$-Z_{sp}$	$\tau_1 \sim p$	PILOT B
Long	q_{Hi}	92.5	A	4.2	1.0	.44	36	A	RATING 5-1/2
									PIO 1

FLT/CONF.	625/3	WIND	Headwind	VISIBILITY	Very hazy
DATE	8/8/80	TURB.	Moderate	AIRPORT	Buffalo

FEEL:
- Forces: Satisfactory
- Displacement:
- Sensitivity:

PITCH ATTITUDE RESPONSE:
- Initial: Satisfactory, a little trim required in turns, doesn't hold attitude perfectly.
- Predictability:
- Special Inputs:
- PIO Tendency:

AIRSPEED CONTROL: Had a problem on one approach. Seemed unusual so tended to ignore that one. Different than behavior on other configuration.

PERFORMANCE:
- Approach Tasks:
  - ILS: Performance a little shabby at times. Think jerkiness caused you to concentrate on certain areas and lose crosscheck. Also external disturbances were causing distractions.
  - Visual (Sidestep): Didn't do visual approaches.
- Landing Tasks: No problem with flare and touchdown.
- Differences: None.

WIND AND TURBULENCE: Crosswind no problem to get out. Ride in turbulence was very noticeable and a problem.

SUMMARY COMMENTS: Just a jerky airplane. You get lateral accelerations in response to an abrupt lateral input. When maneuvering you get it stirred up easily.

Flt/Conf. 62S/3

PILOT COMMENTS

LATERAL-DIRECTIONAL

ROLL CONTROL	Jerkiness in roll.
Authority	Authority was enough.
Sensitivity	O.K.
Response	Didn't feel smooth.
Overshoot Tendency	None
HEADING RESPONSE	Not well coordinated in terms of side acceleration.
Turn Entry Rollout of turn	Ball shoots off the opposite direction, right turn, left ball. Needed right rudder in right turn to get turn rate for the bank angle.
TENDENCY TO SIDESLIP FOR ROLL MANEUVERS	There was some sideslip in roll maneuvers
RUDDER CONTROL	
Authority	O.K.
Sensitivity	O.K.
TENDENCY TO HOLD BANK	Could maintain bank angle but I was getting confused at times with how to coordinate, get reasonable turn rates.
ROLL-PITCH CONTROL HARMONY	Harmony with pitch was less than desirable.
RIDE QUALITY Lateral Accel.	Poor. Initial accelerations were noticeable and unusual. In the steady state, nothing there.
Turbulence	Poor ride quality. Very noticeable, large disturbances outside were feeding through.
Input Magnitude causing objectional lateral accel.	Accelerations unsatisfactory.
MAJOR PROBLEMS	General feeling of lack of coordination and jerkiness.
GOOD FEATURES	---

Appendix IV

OPEN-LOOP AIRCRAFT PLUS COMPENSATED PILOT NICHOLS DIAGRAMS, $\theta/\theta_\varepsilon$

This appendix presents the open-loop aircraft plus compensated pilot Nichols diagrams for each configuration evaluated. The pilot model contains a .25 second delay and low frequency integration capability $\left(\frac{5s+1}{s}\right)$.

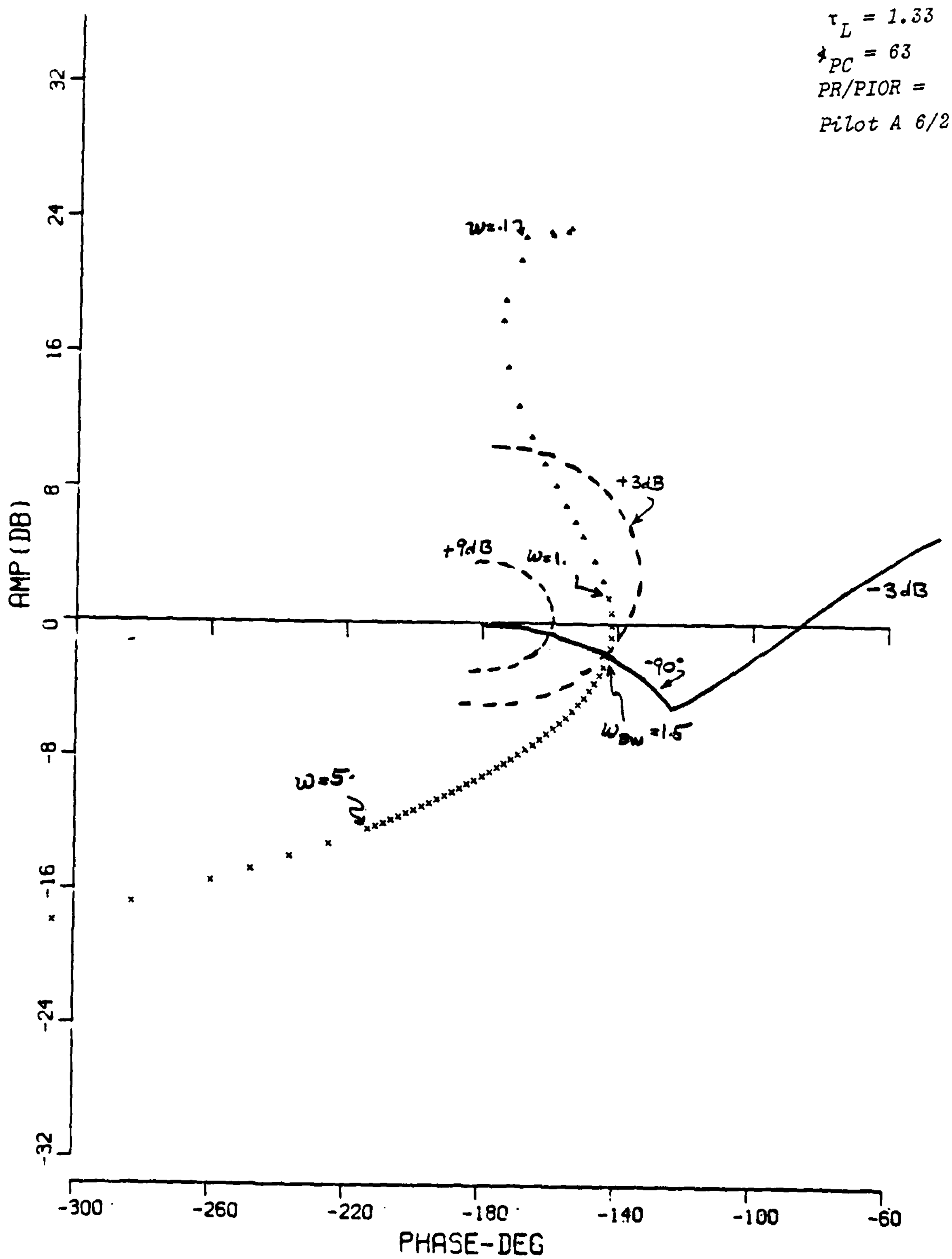
$$\theta/\theta_\varepsilon = K_{P_\theta}\ (\tau_L s+1)e^{-.25s}\left(\frac{5s+1}{s}\right)\theta/F_{ES}$$

The gain (K_{P_θ}) and lead compensation ($\tau_L s+1$) was adjusted to achieve a closed-loop bandwidth (ω_{BW_θ}) of 1.5 rad/sec without violating the closed-loop droop and resonance boundaries. The solution requiring minimum pilot lead was selected in most cases. The pilot compensation is discussed in Section 4.3.2.

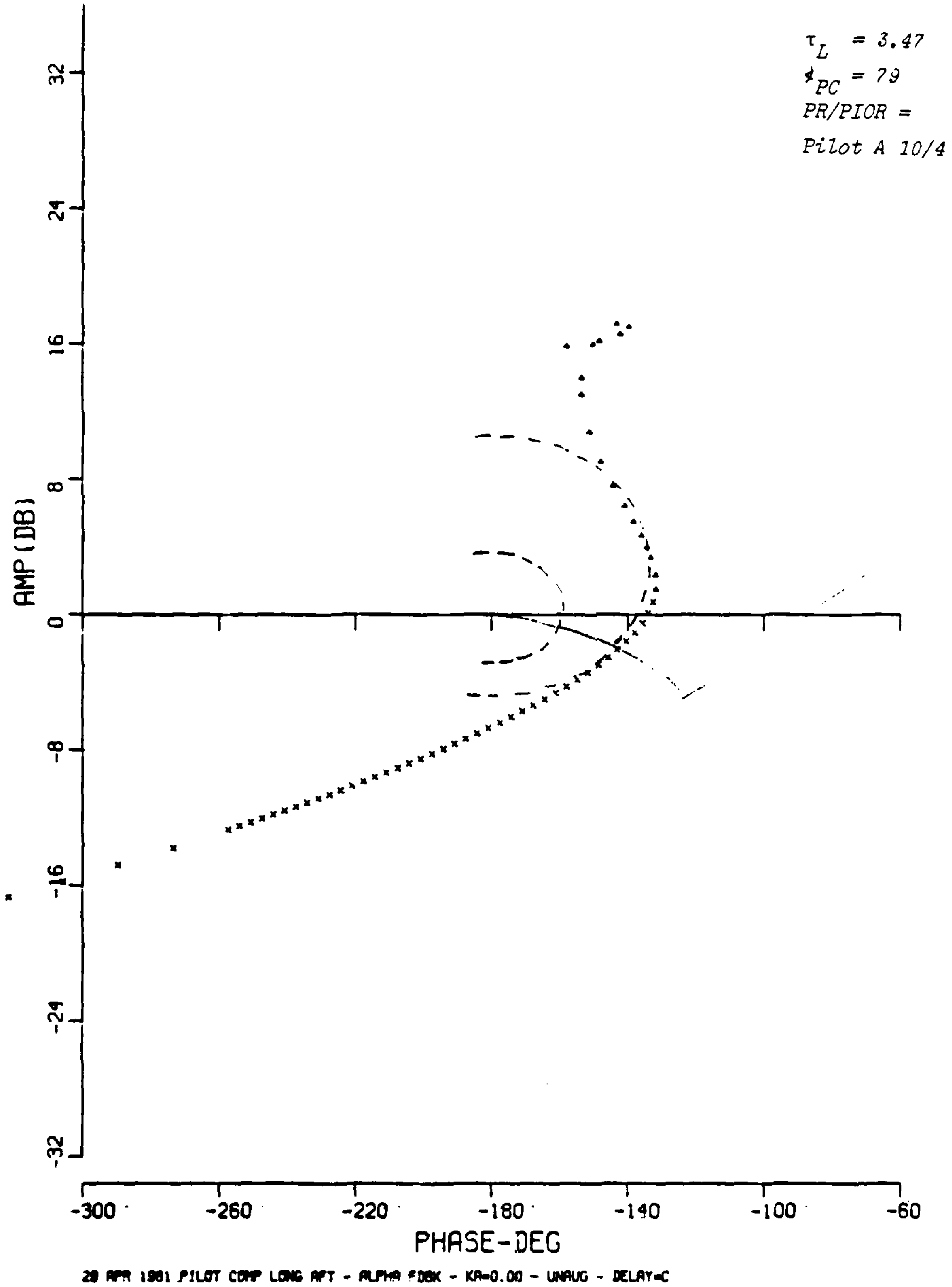
The closed-loop analysis was performed using the 25 rad/sec feel system for all configurations. The caption on each plot defines the configuration. Also drawn on each plot are the closed-loop +3 dB, +9 dB resonance; -3 dB droop, and -90 degrees phase lines. The 1.5 rad/sec point passes through the -90 degree phase line indicating the closed-loop bandwidth. Listed on each plot is the lead time constant used, phase compensation at ω_{BW} and pilot rating/PIO rating received. The order of the frequency points is:

(rad/sec) ▲ = .1, .12, .14, .16, .2, .24, .28, .3, .35, .4, .45, .5, .55, .6, .65, .7, .8, .9

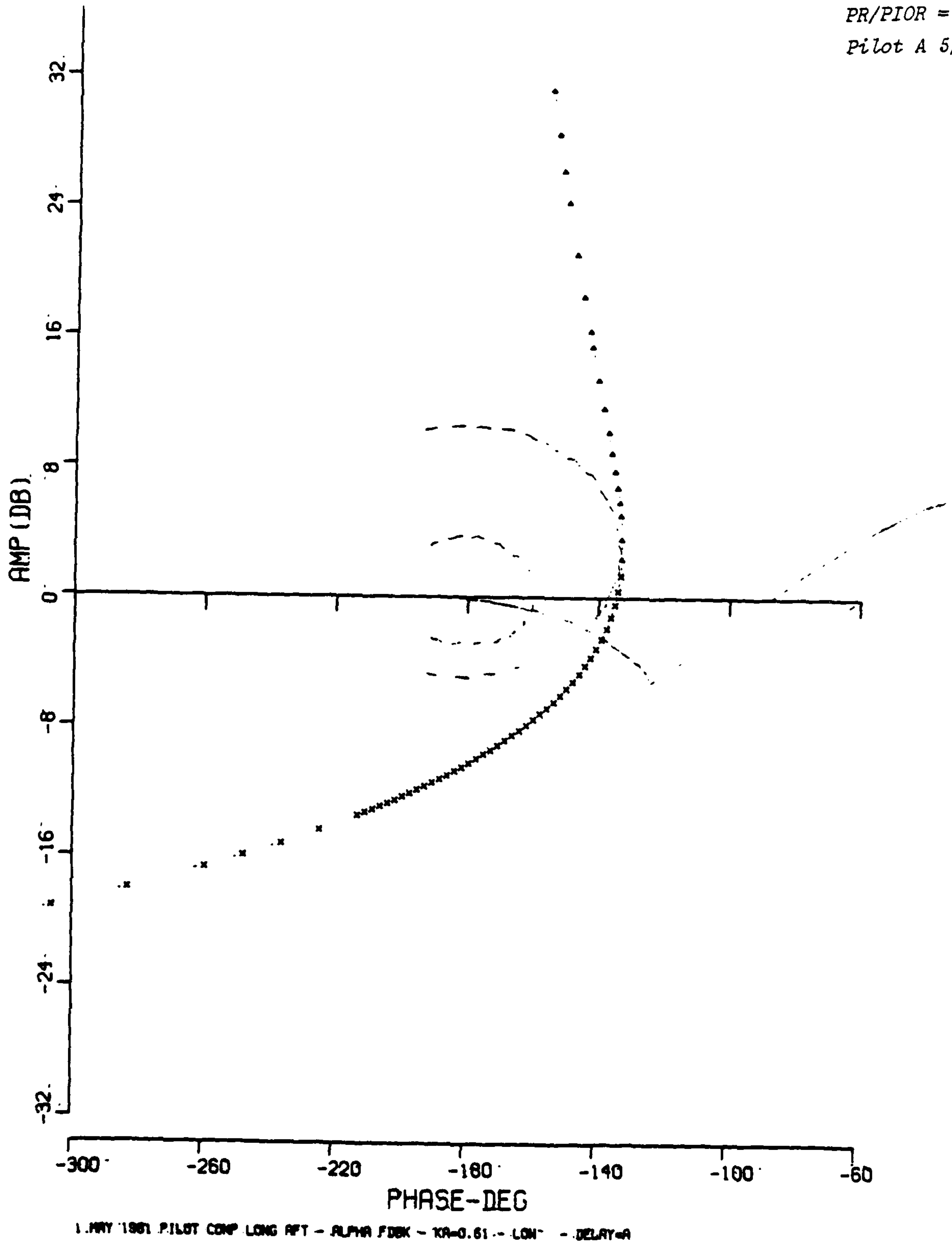
X = 1., 1.1, 1.2, 1.3, 1.4, 1.5, 1.6, 1.7, 1.8, 1.9, 2., 2.1, 2.2, 2.3, 2.4, 2.5, 2.6, 2.7, 2.8, 2.9, 3., 3.1, 3.2, 3.3, 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 4., 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, 5., 5.5, 6., 6.5, 7., 8., 9., 10.

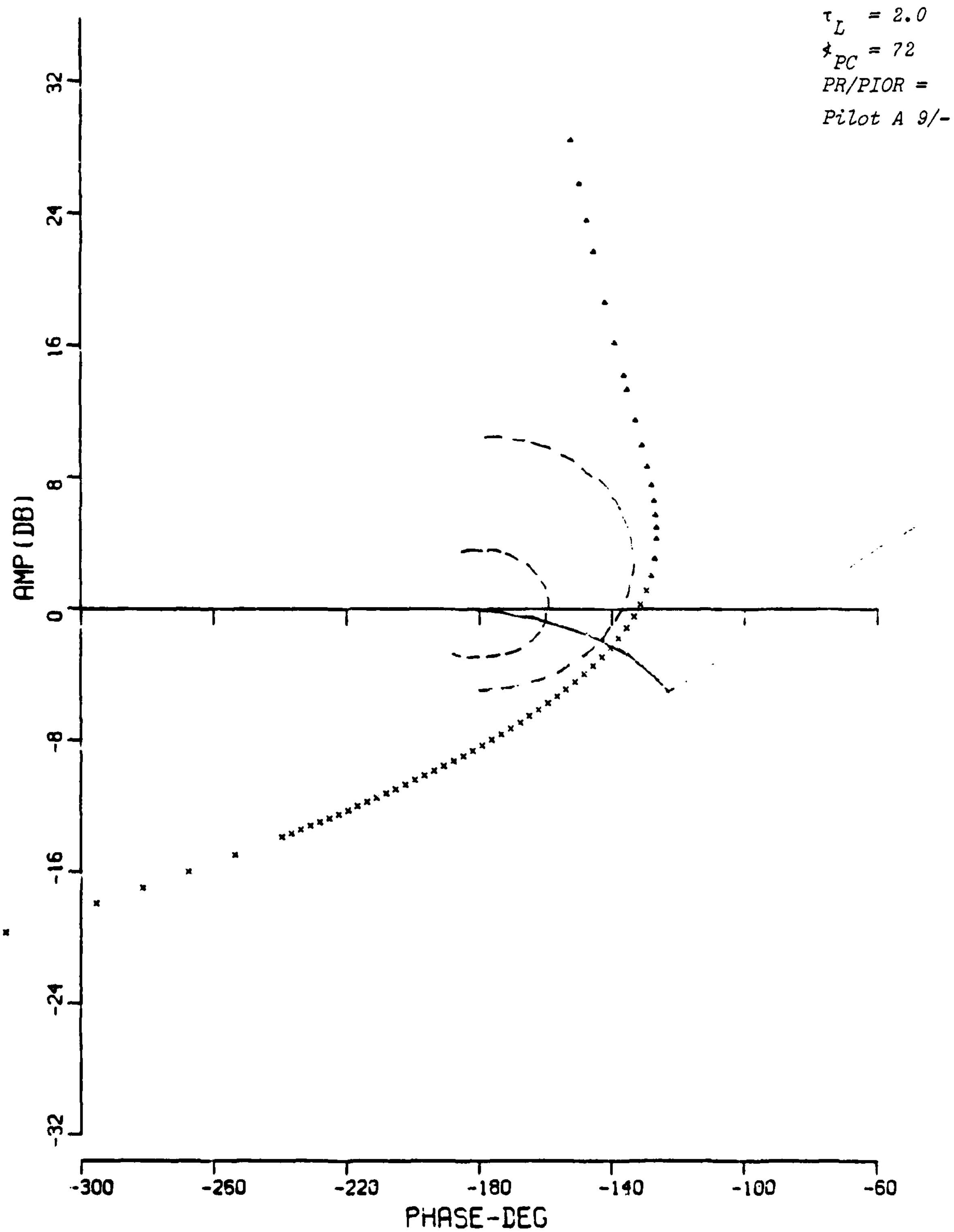


29 APR 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=0.00 - UNAUG - DELAY=A


τ_L = 3.47
ϕ_{PC} = 79
PR/PIOR =
Pilot A 10/4
32
24
16
8
0
-8
-16
-24
-32
AMP (DB)
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
29 APR 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=0.00 - UNAUG - DELAY=C

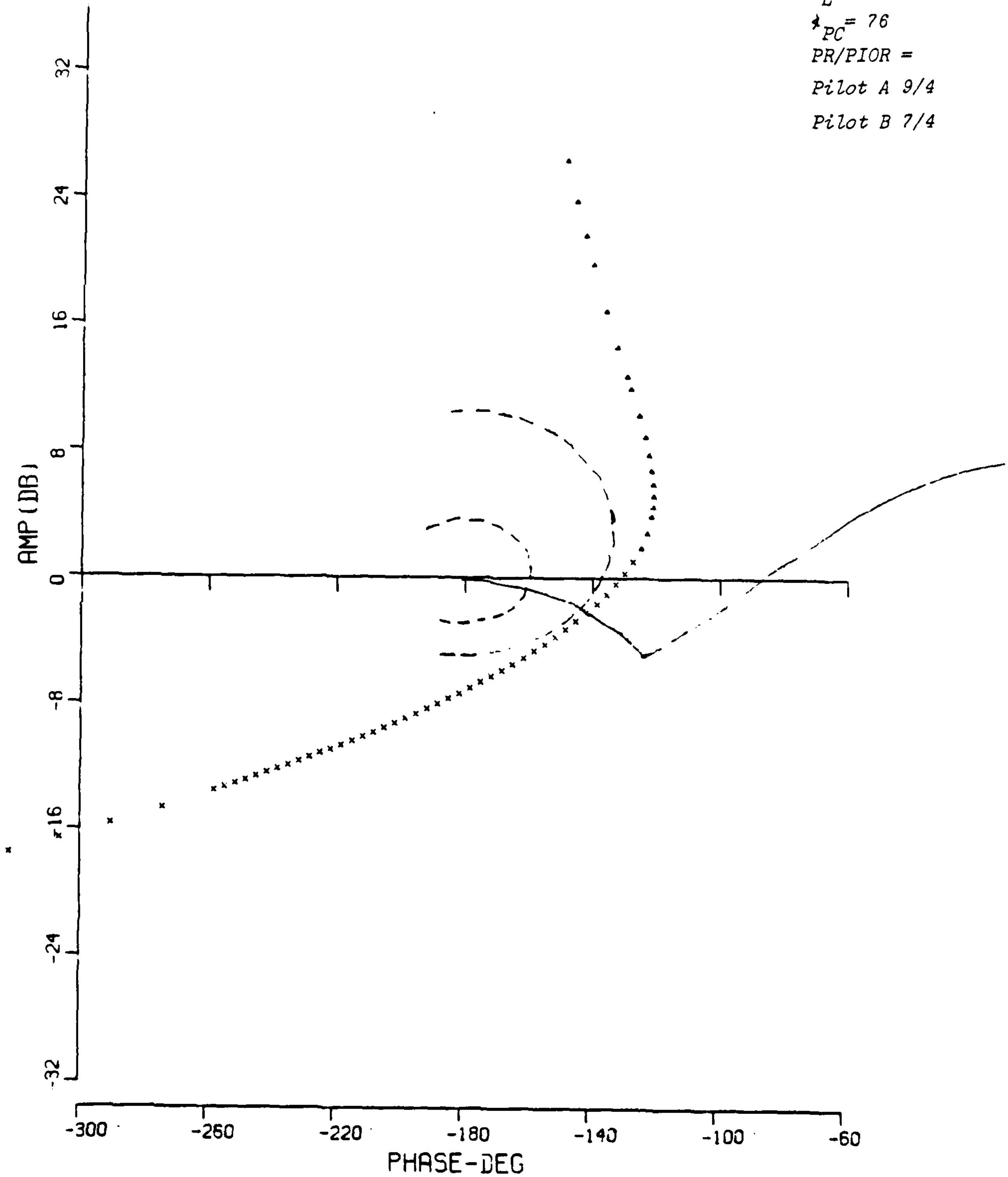
$\tau_L = 1.33$
$\phi_{PC} = 63$
PR/PIOR =
Pilot A 5/1



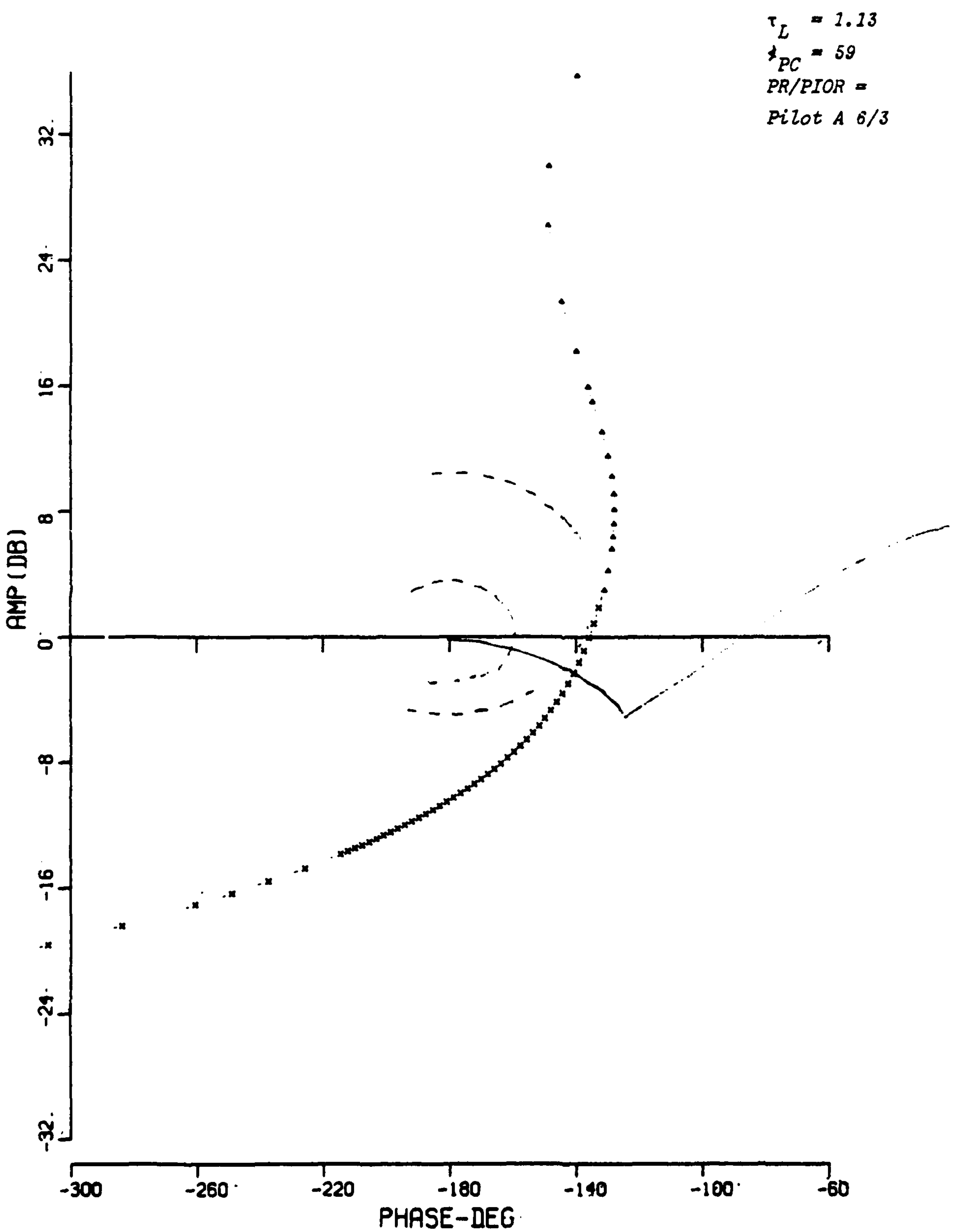


28 APR 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=0.61 - LOW - DELAY=8

$\tau_L = 2.7$
$\phi_{PC} = 76$
PR/PIOR =
Pilot A 9/4
Pilot B 7/4

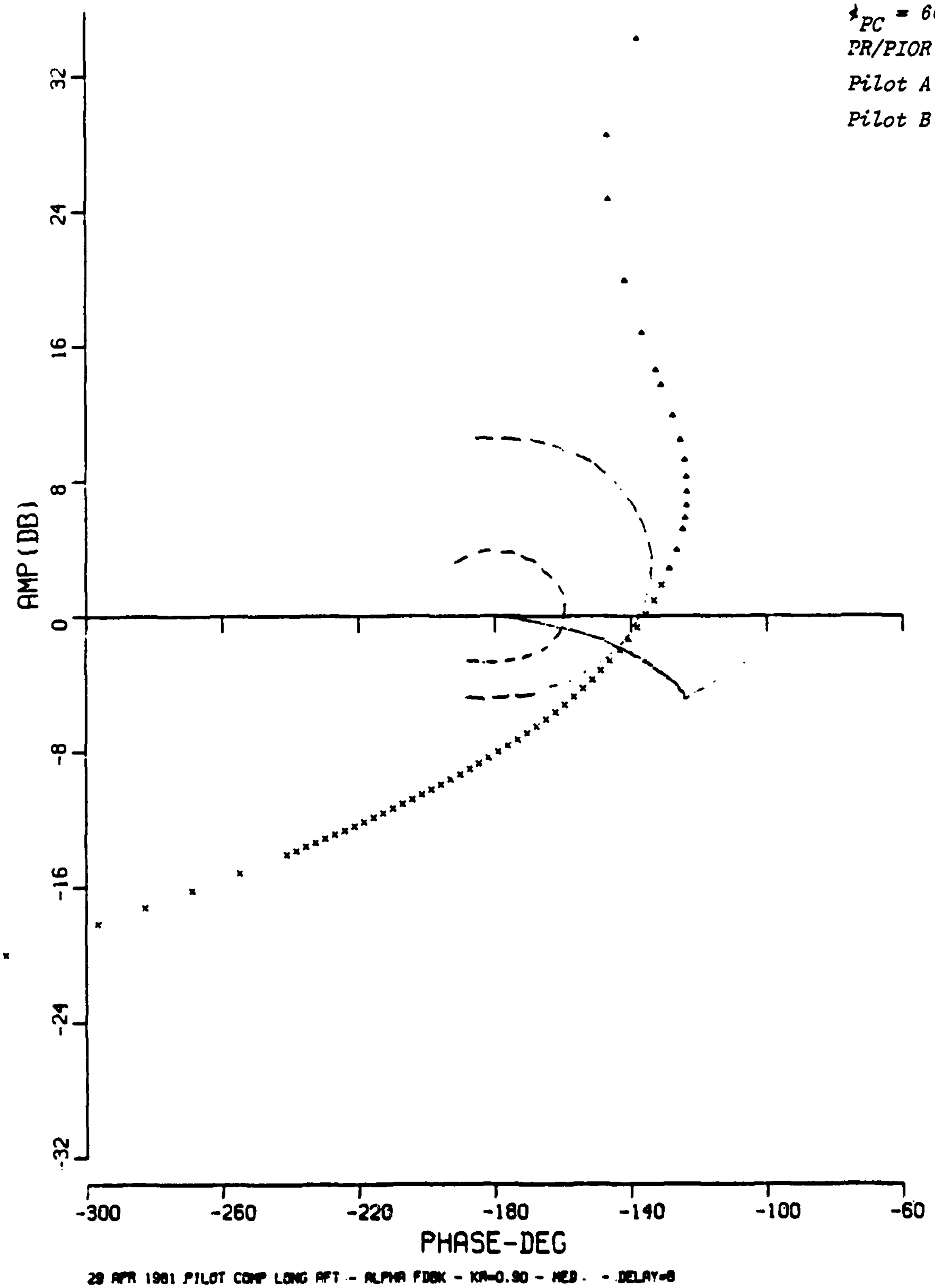


29 APR 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=0.61 - LOW - DELAY=C



1 MAY 1981 PILOT COMP LONG AFT -- ALPHA FDBK - KA=0.90 - MED- - DELAY=A

$\tau_L = 1.53$
$\phi_{PC} = 66$
PR/PIOR =
Pilot A 7/3
Pilot B 5/1

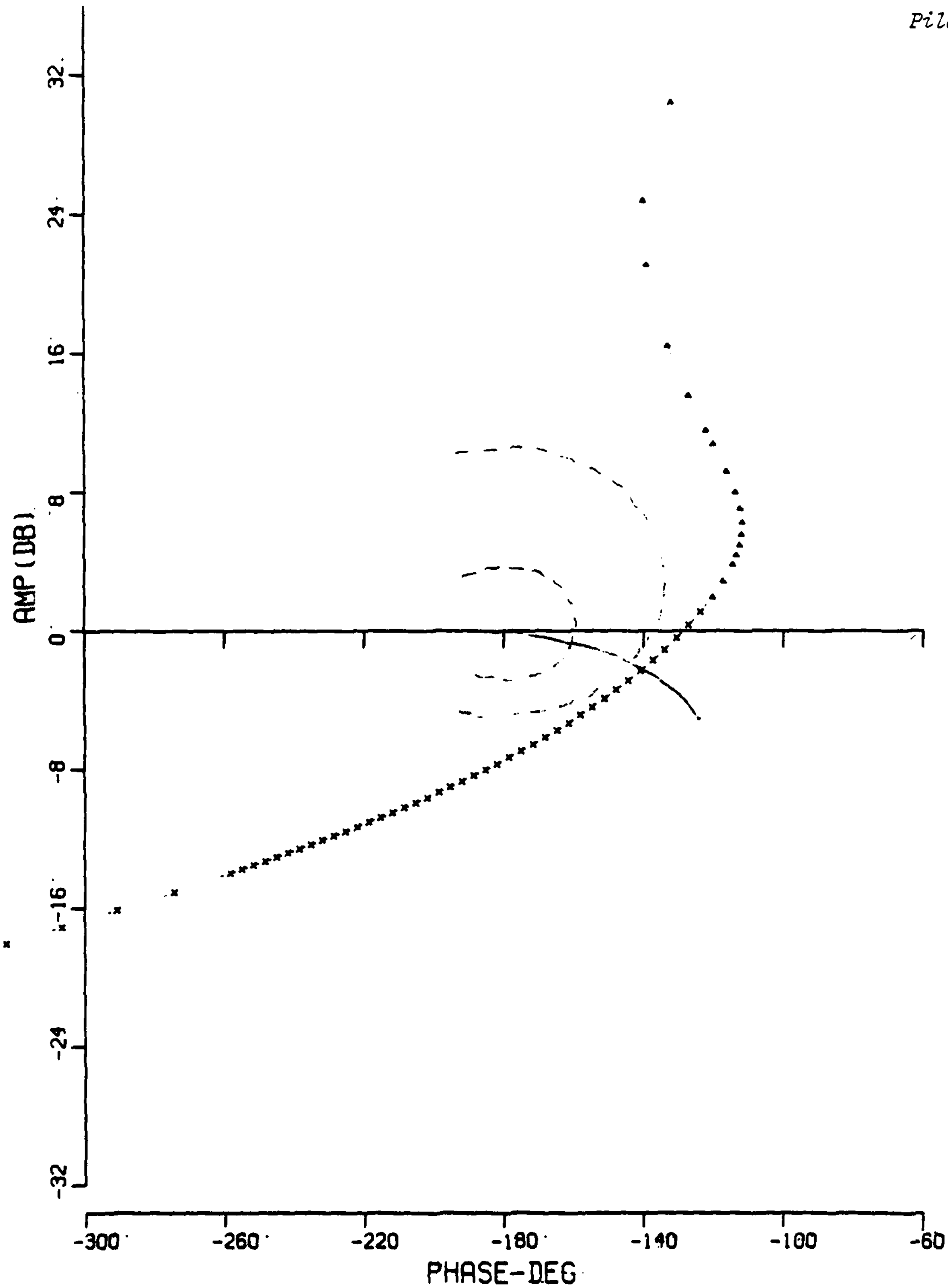


$\tau_L = 2.47$

$\phi_{PC} = 75$

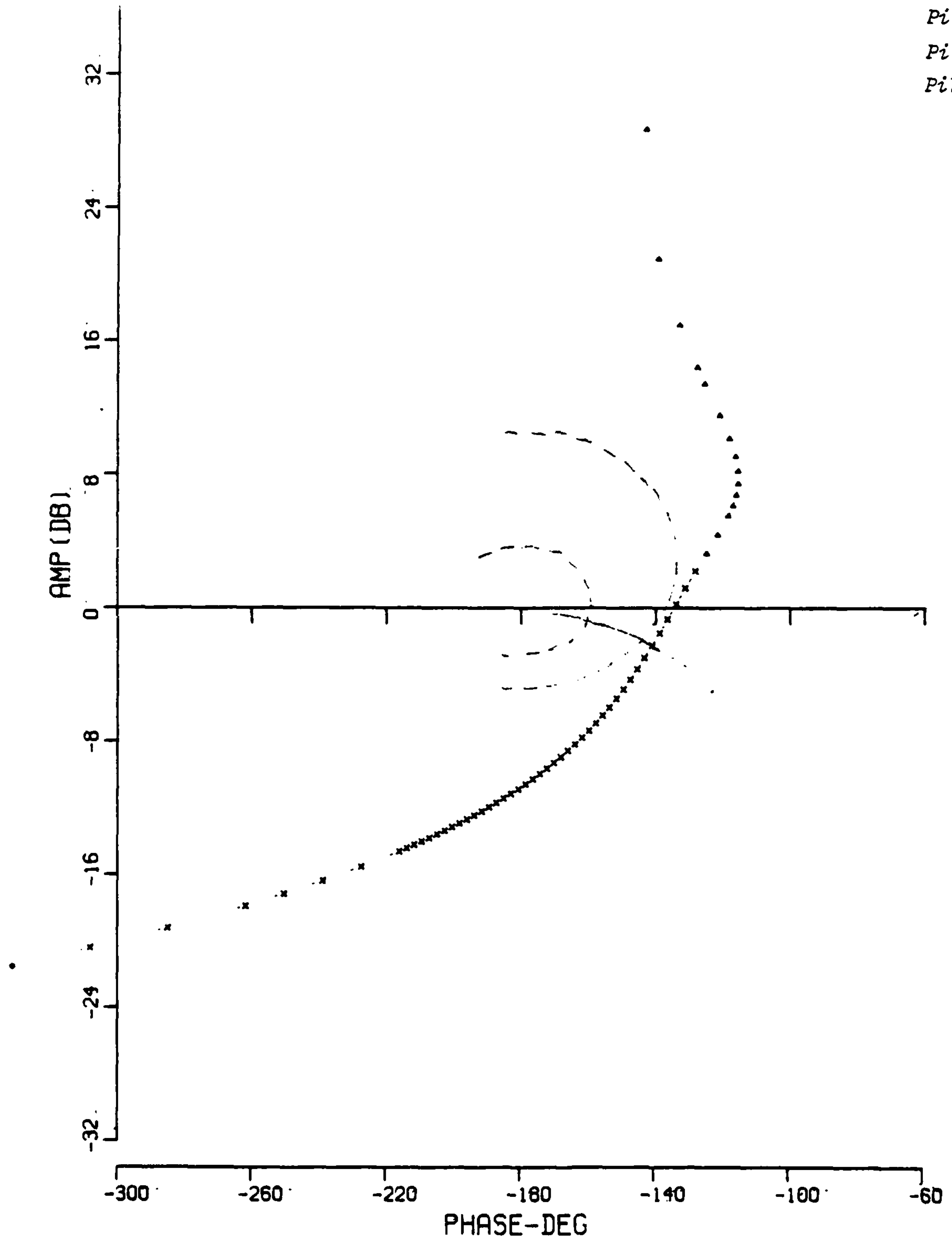
PR/PIOR =

Pilot A 8/4



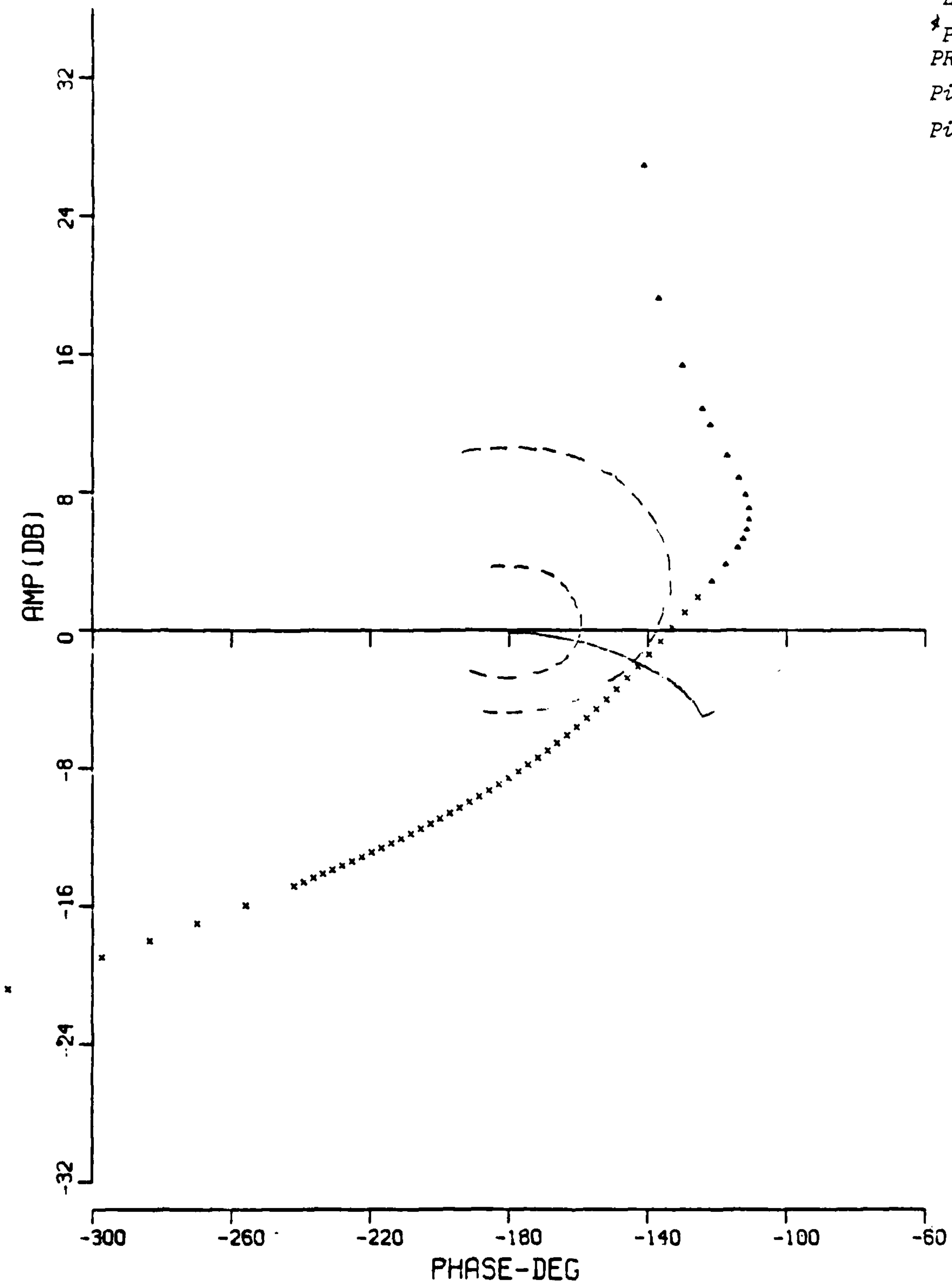
1 MAY 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=0.90 - MED - DELAY=C

τ_L = .97
$\measuredangle_{PC}$ = 55
PR/PIOR =
Pilot A 5/2
Pilot A 6/3
Pilot B 2/1

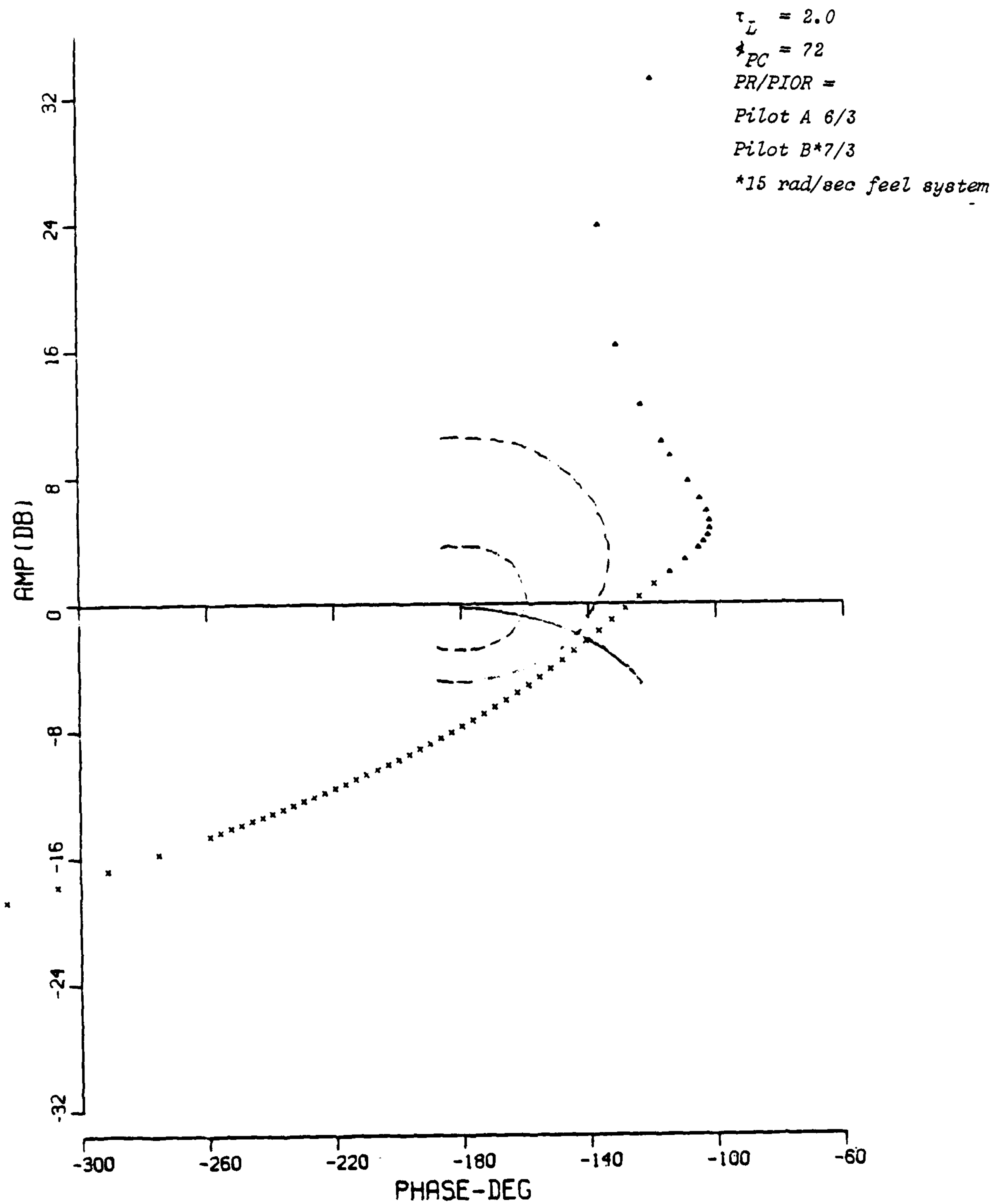


1 MAY 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=1.35 - HI - DELAY=A

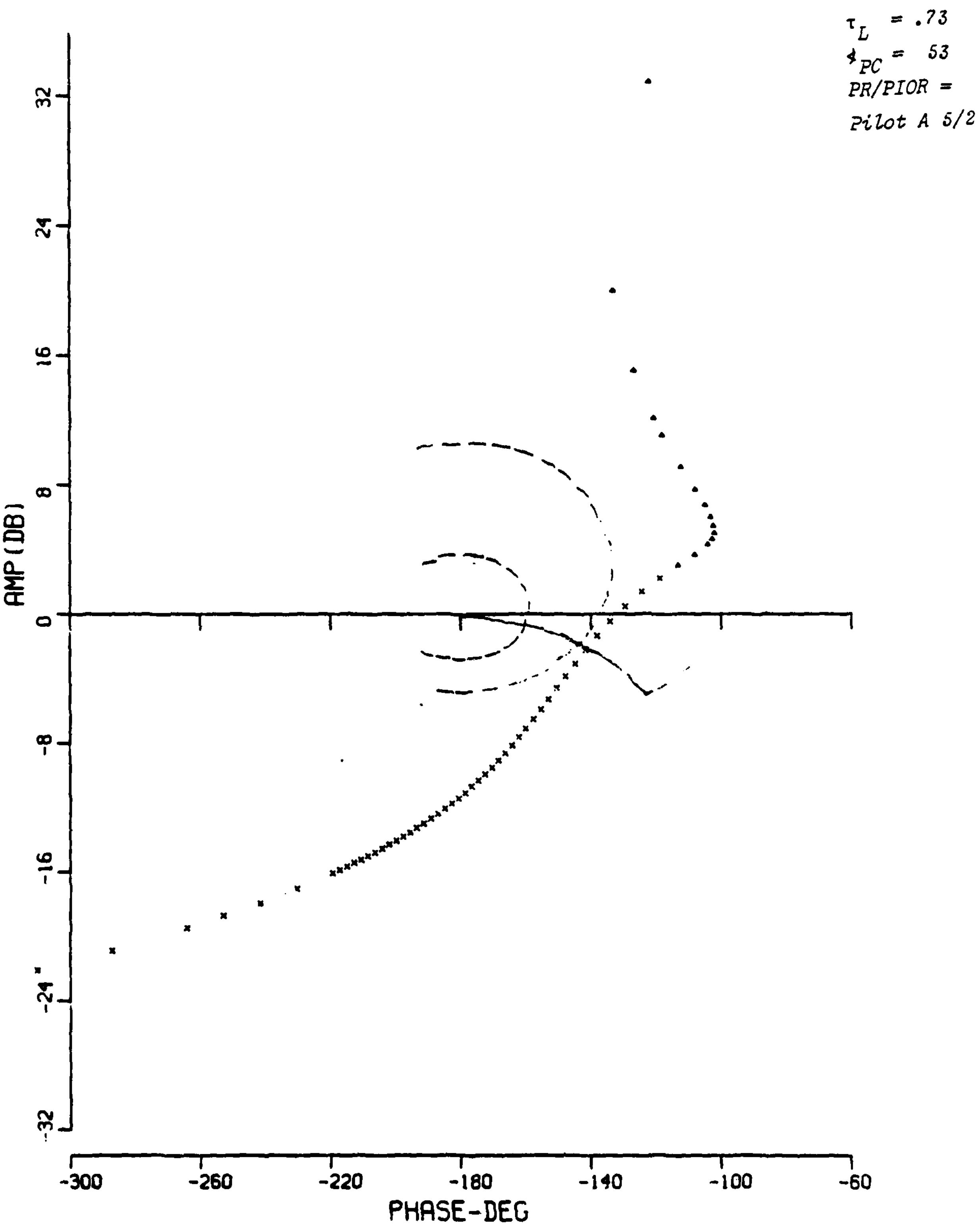
$\tau_L = 1.33$
$\phi_{PC} = 63$
PR/PIOR =
Pilot A 7/4
Pilot A 6/3



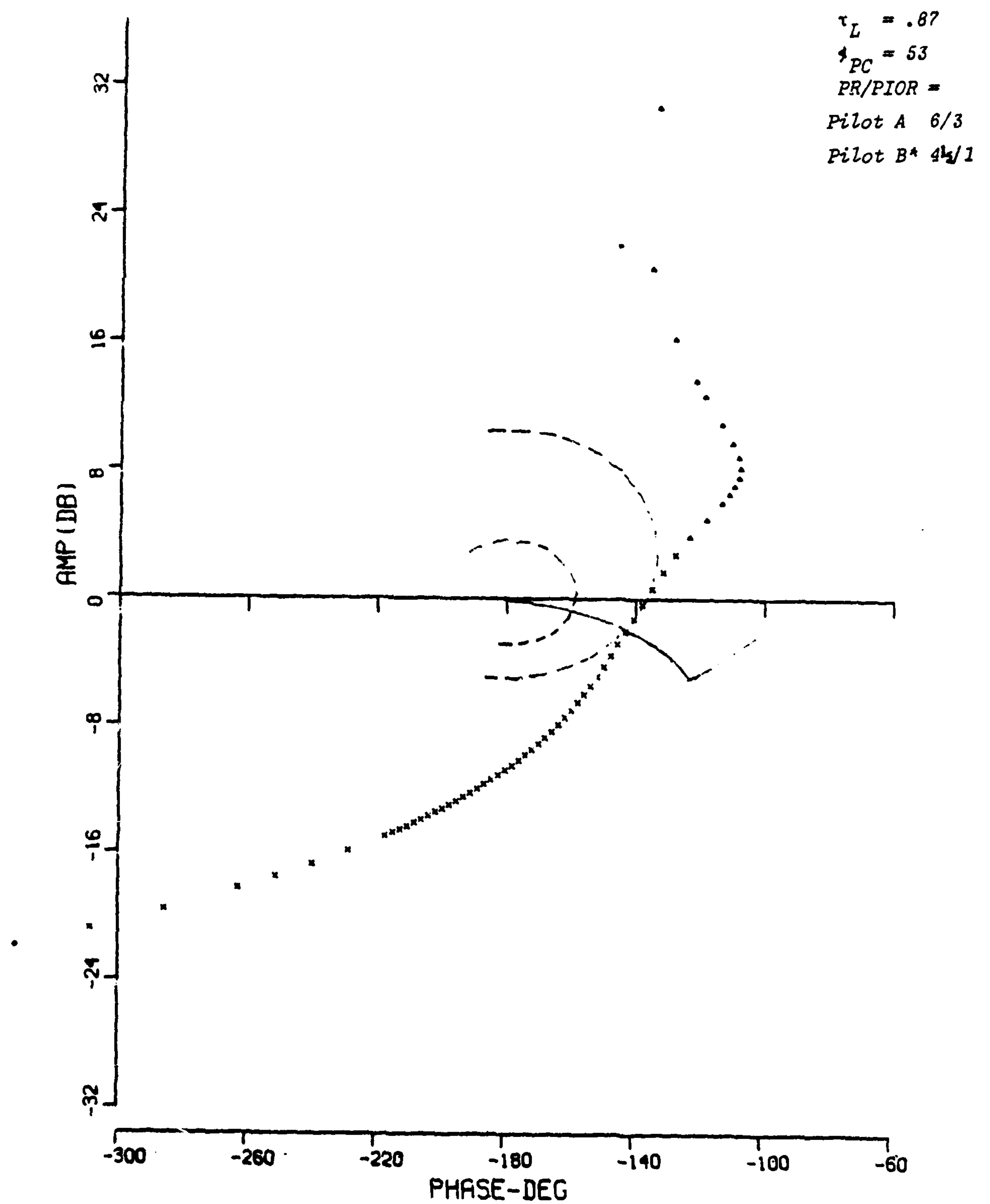
20 APR 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=1.35 - HI - DELAY=0



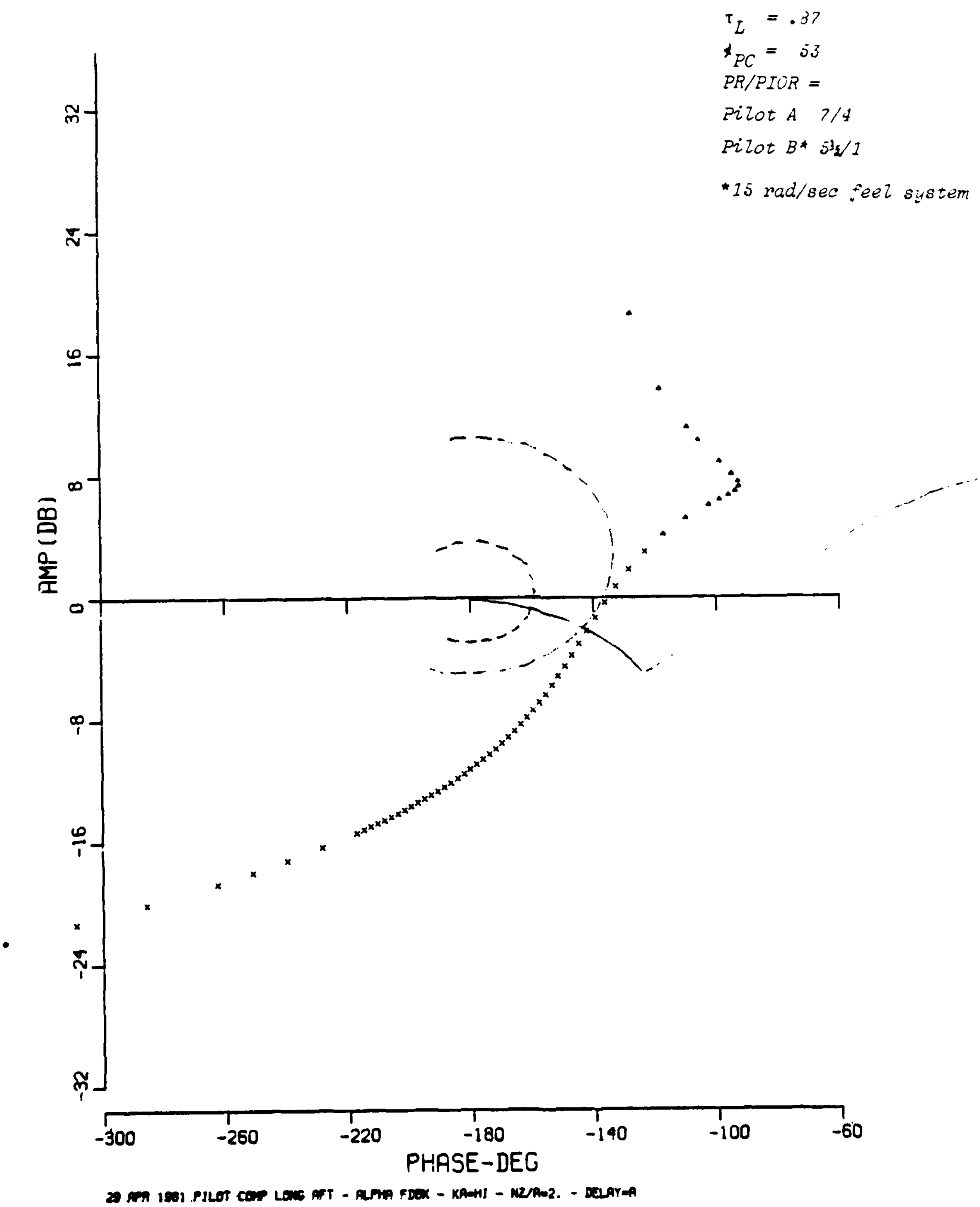
28 APR 1981 PILOT COMP LONG APT - ALPHA FDBK - KA=1.35 - HI - DELAY=C



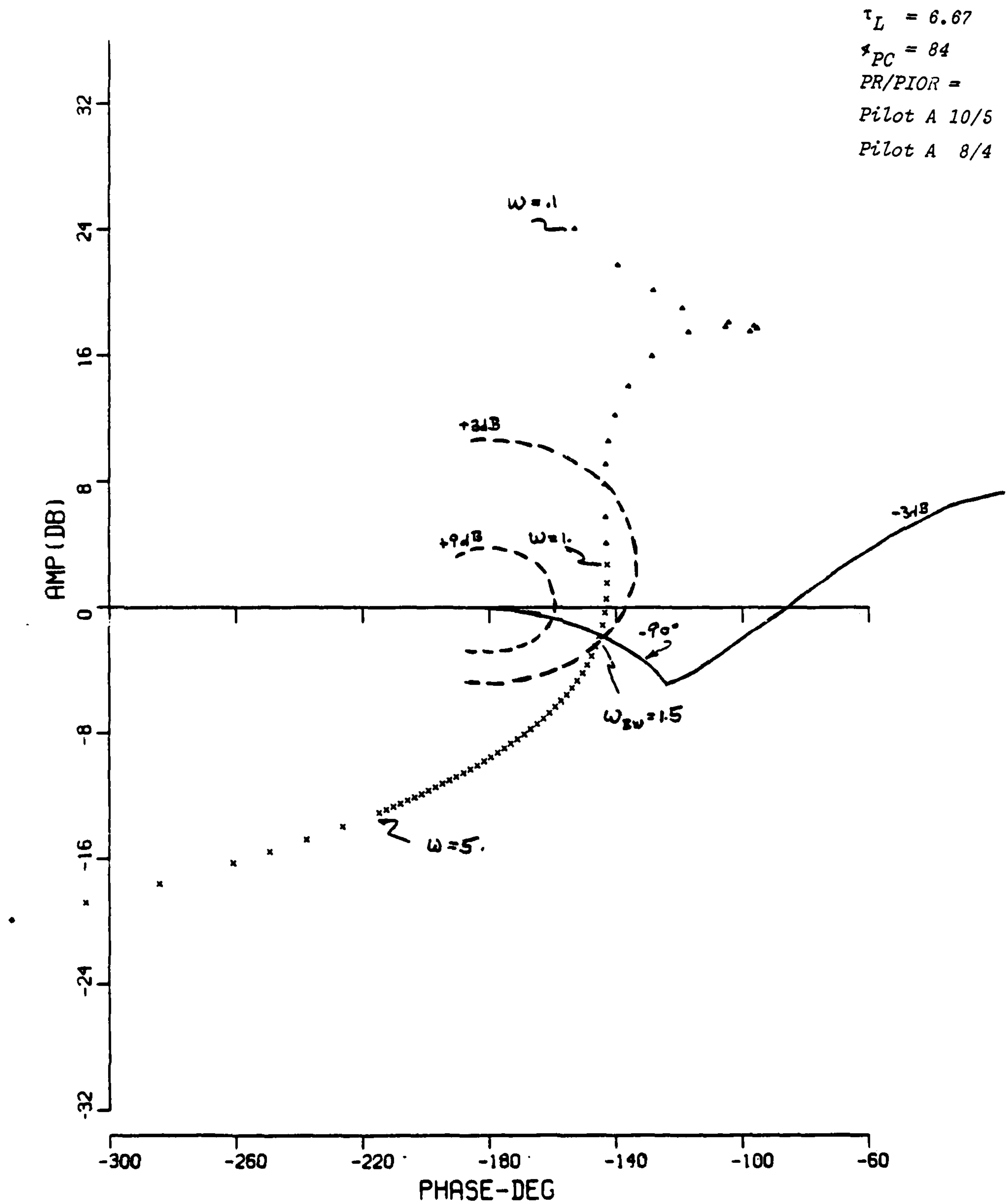
28 APR 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=2.10 - EX-HI - DELAY=A



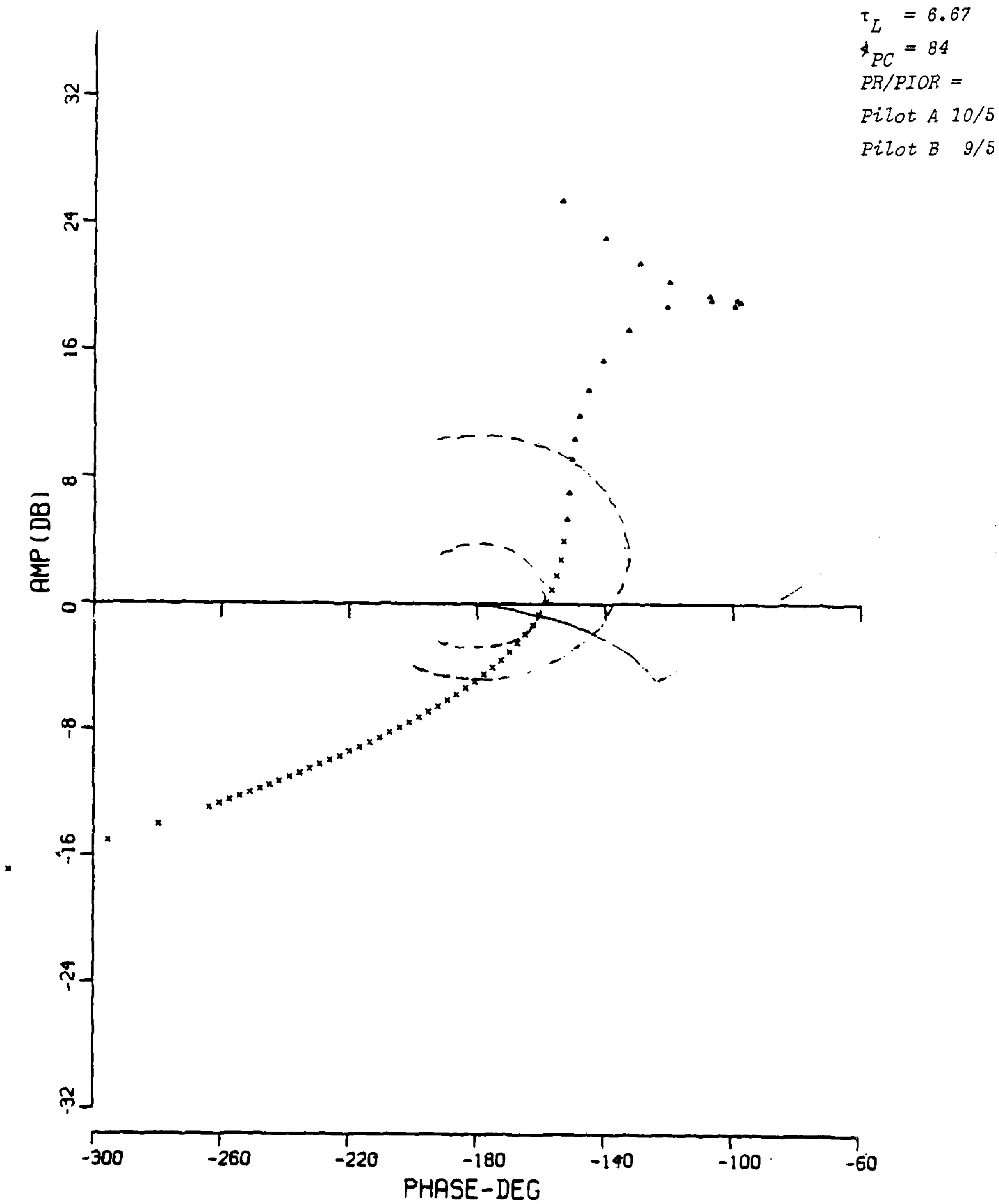
28 APR 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=HI - NZ/A=3. - DELAY=A



τ_L = .37
ϕ_{PC} = 53
PR/PIOR =
Pilot A 7/4
Pilot B* 5½/1
*15 rad/sec feel system
32
24
16
8
0
-8
-16
-24
-32
AMP (DB)
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
29 APR 1981 PILOT COMP LONG AFT - ALPHA FDBK - KA=HI - NZ/A=2. - DELAY=A

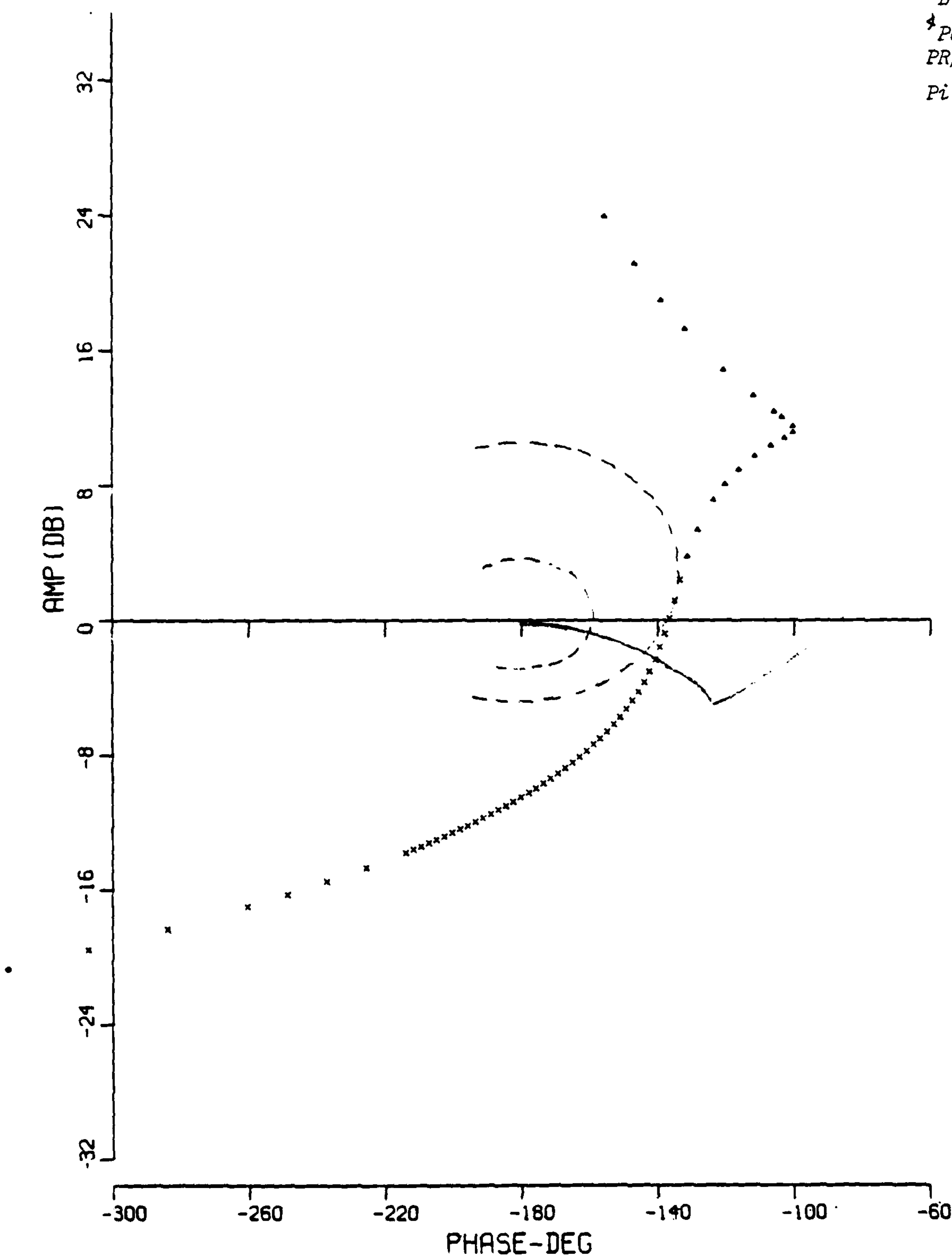


28 APR 1981 PILOT COMP LONG AFT - Q FDBK-TO=1. - KQ=0.60 - LOW - DELAY=A



29 APR 1981 PILOT COMP LONG AFT - Q FDBK-TQ=1. - KQ=0.60 - LOW - DELAY=C

τ_L = 2.53
ϕ_{PC} = 75
PR/PIOR =
Pilot A 4½/3



29 APR 1981 PILOT COMP LONG AFT - Q FDBK-TO=1. - KQ=1.30 - MED - DELAY=A

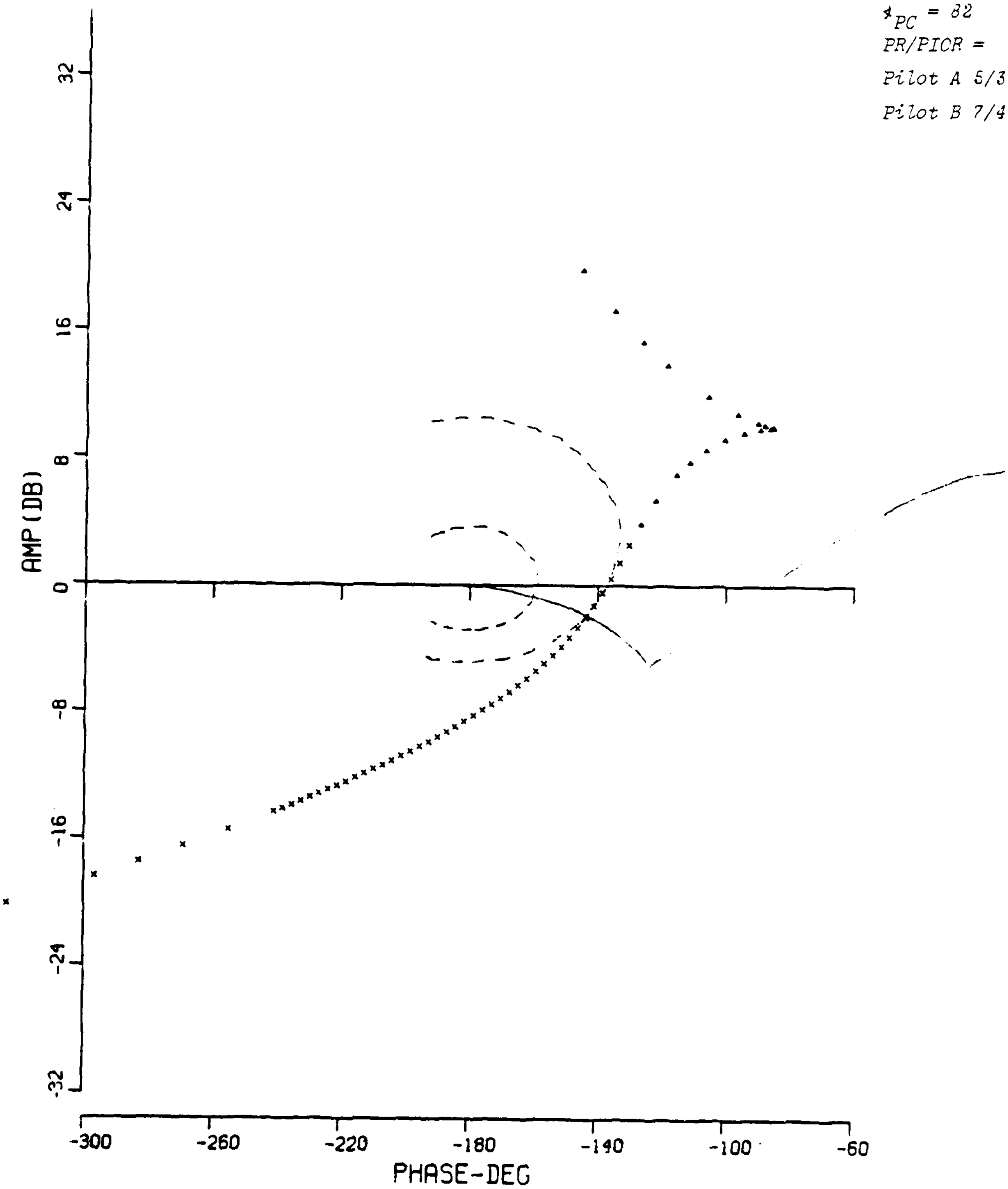
$\tau_L = 4.67$

$\measuredangle_{PC} = 82$

PR/PICR =

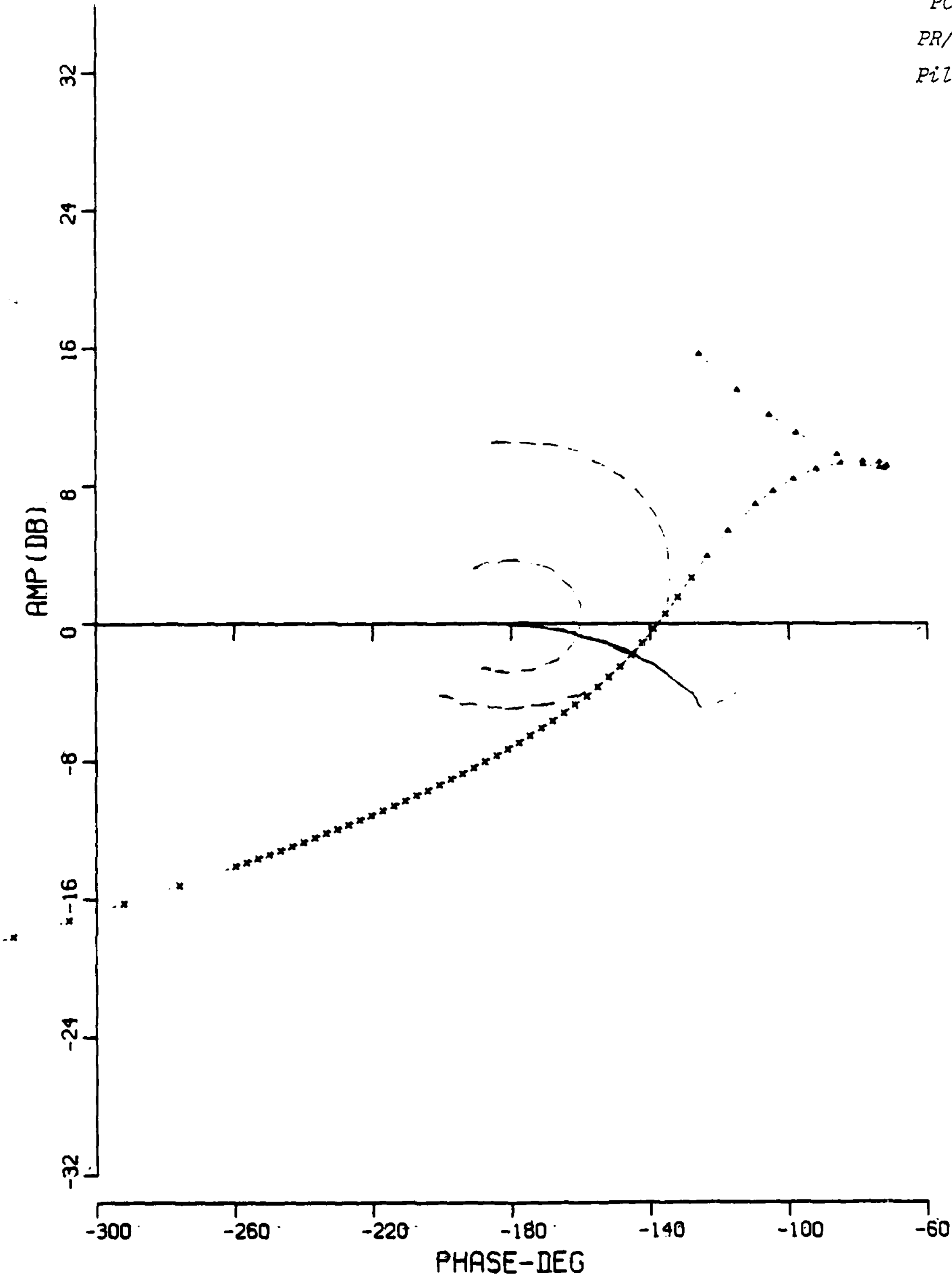
Pilot A 5/3

Pilot B 7/4

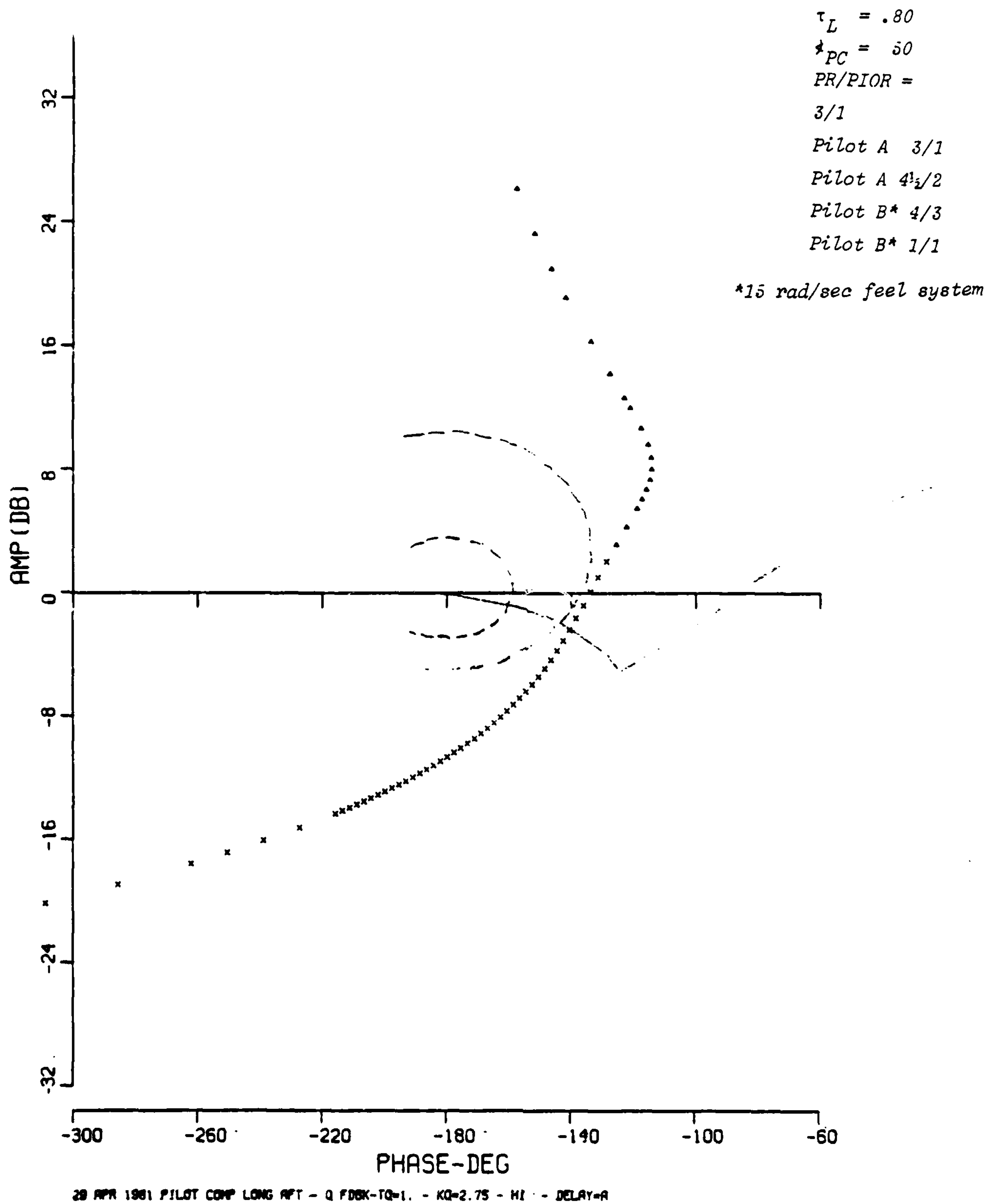


29 APR 1981 PILOT COMP LONG AFT - Q FDBK-TQ=1. - KQ=1.30 - MED - DELAY=8

τ_L = 10.0
$\measuredangle_{PC}$ = 86
PR/PIOR =
Pilot A 6/4



1 MAY 1981 PILOT COMP LONG AFT - Q FDBK-TQ=1. - KQ=1.30 - MED - DELAY=C



τL = .80
∮PC = 50
PR/PIOR =
3/1
Pilot A 3/1
Pilot A 4½/2
Pilot B* 4/3
Pilot B* 1/1
*15 rad/sec feel system
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
20 APR 1981 PILOT COMP LONG AFT - Q FDBK-TQ=1. - KQ=2.75 - HI - DELAY=A

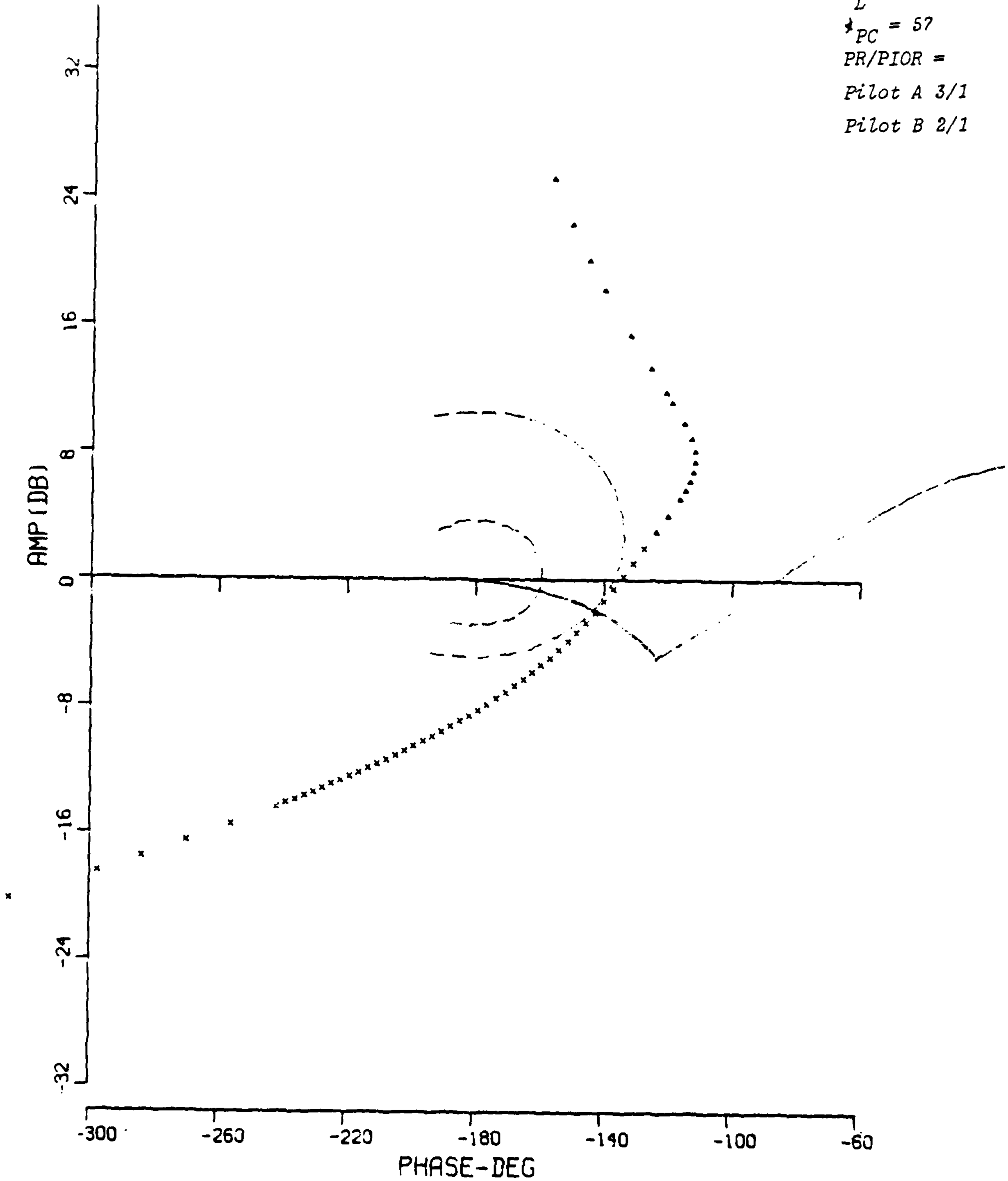
τ_L = 1.03

ϕ_{PC} = 57

PR/PIOR =

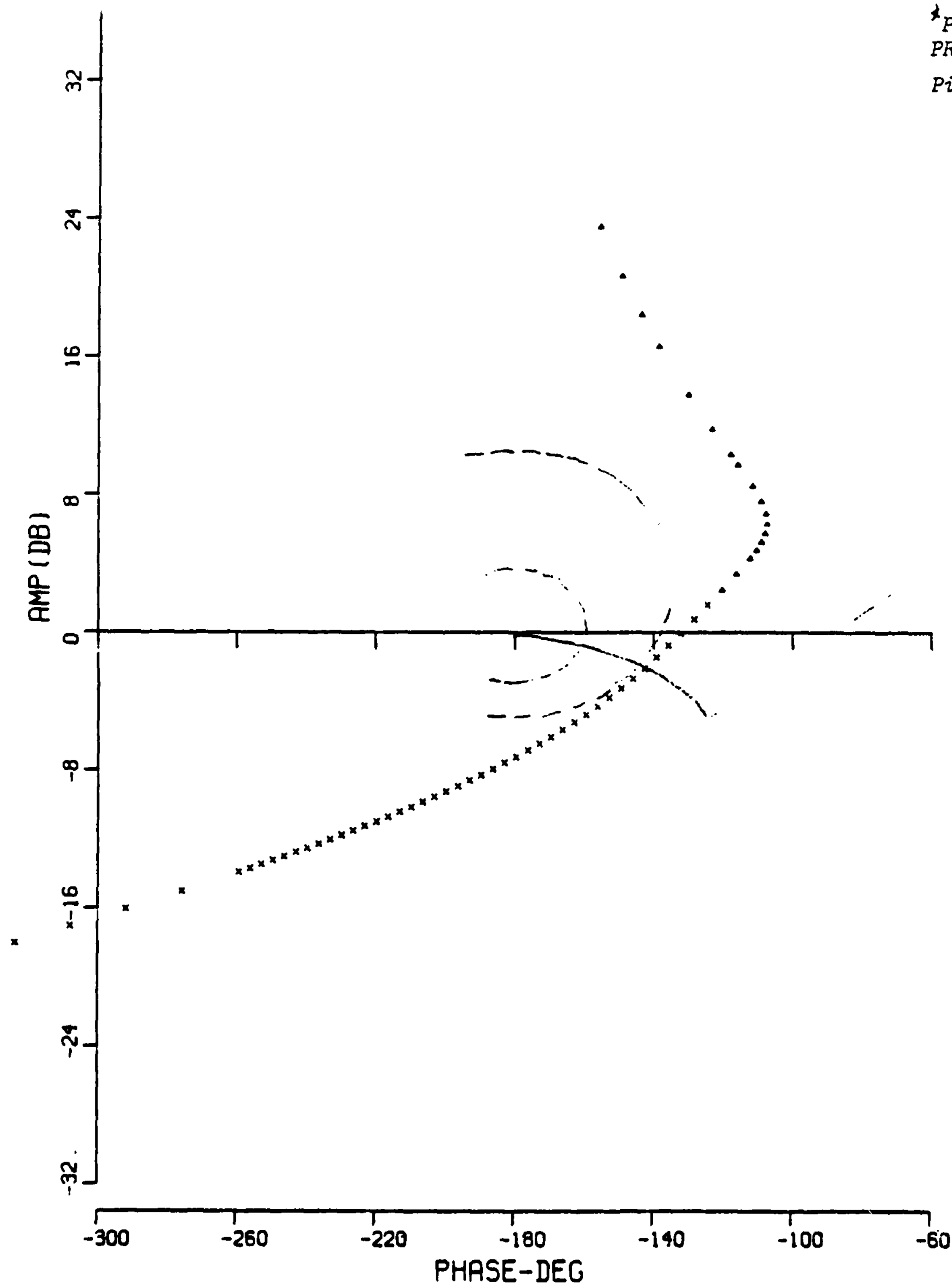
Pilot A 3/1

Pilot B 2/1

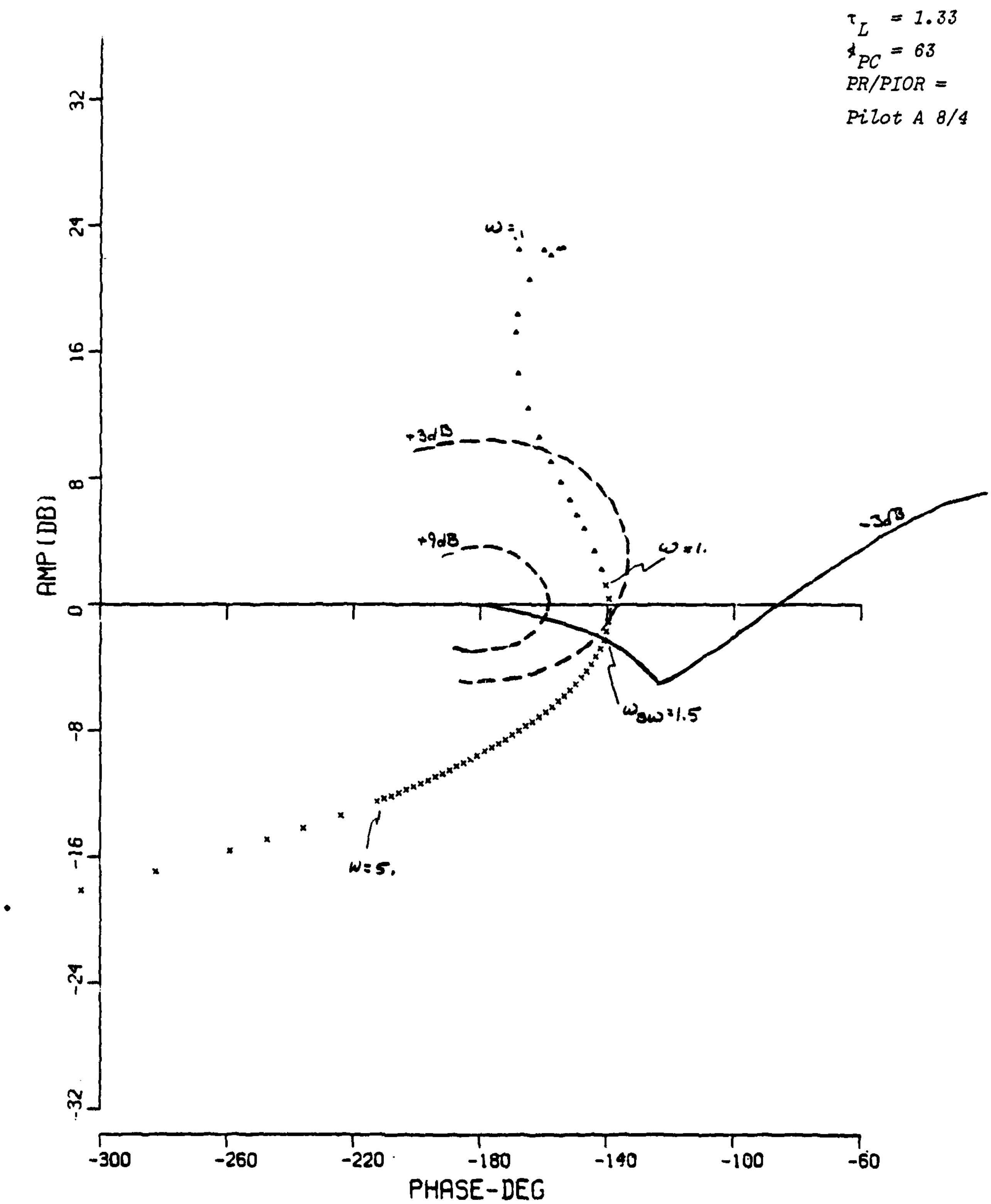


29 APR 1981 PILOT COMP LONG AFT - Q FDBK-TQ=1. - KQ=2.75 - HI - DELAY=8

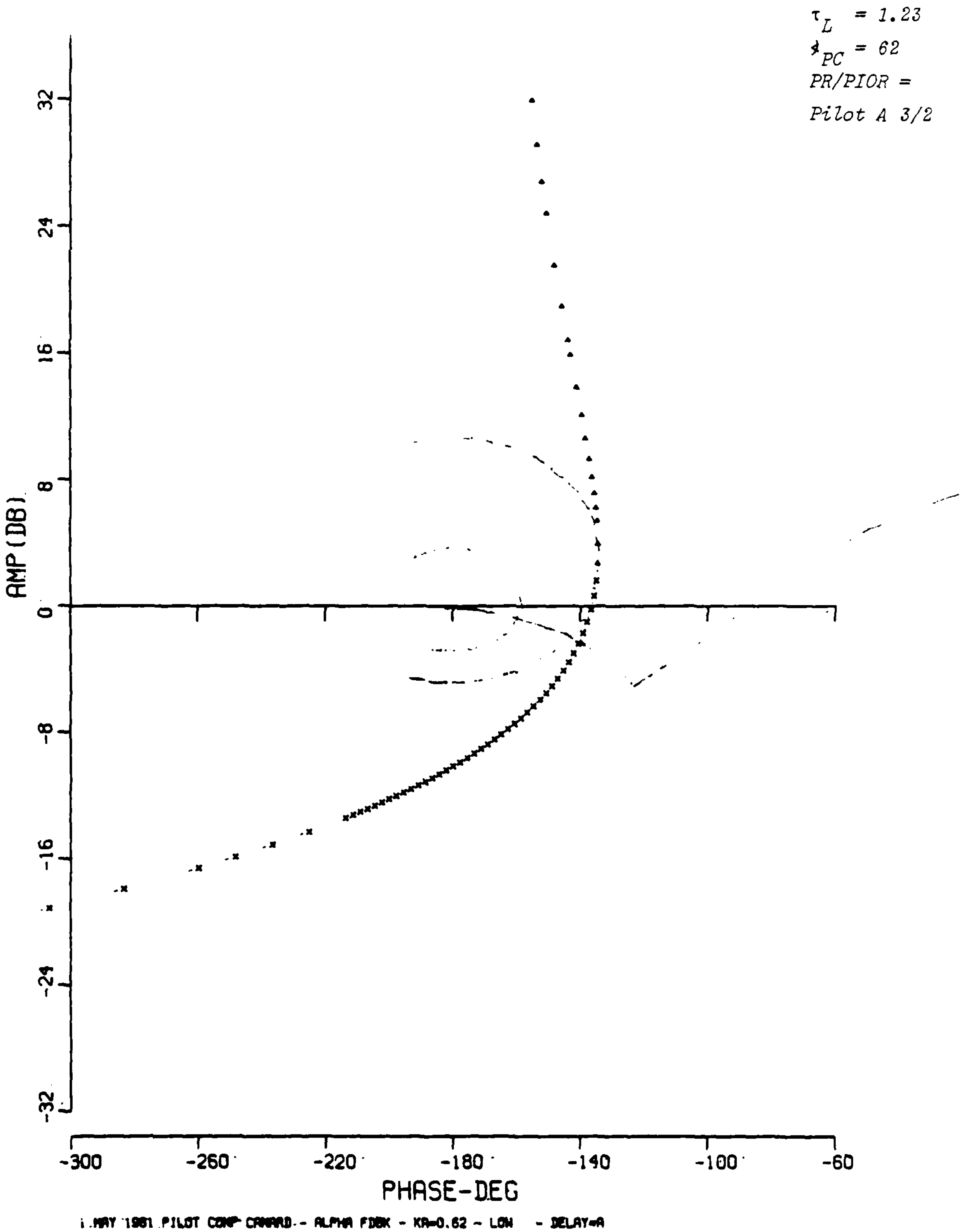
$\tau_L = 1.33$
$\measuredangle_{PC} = 63$
PR/PIOR =
Pilot A 5/4



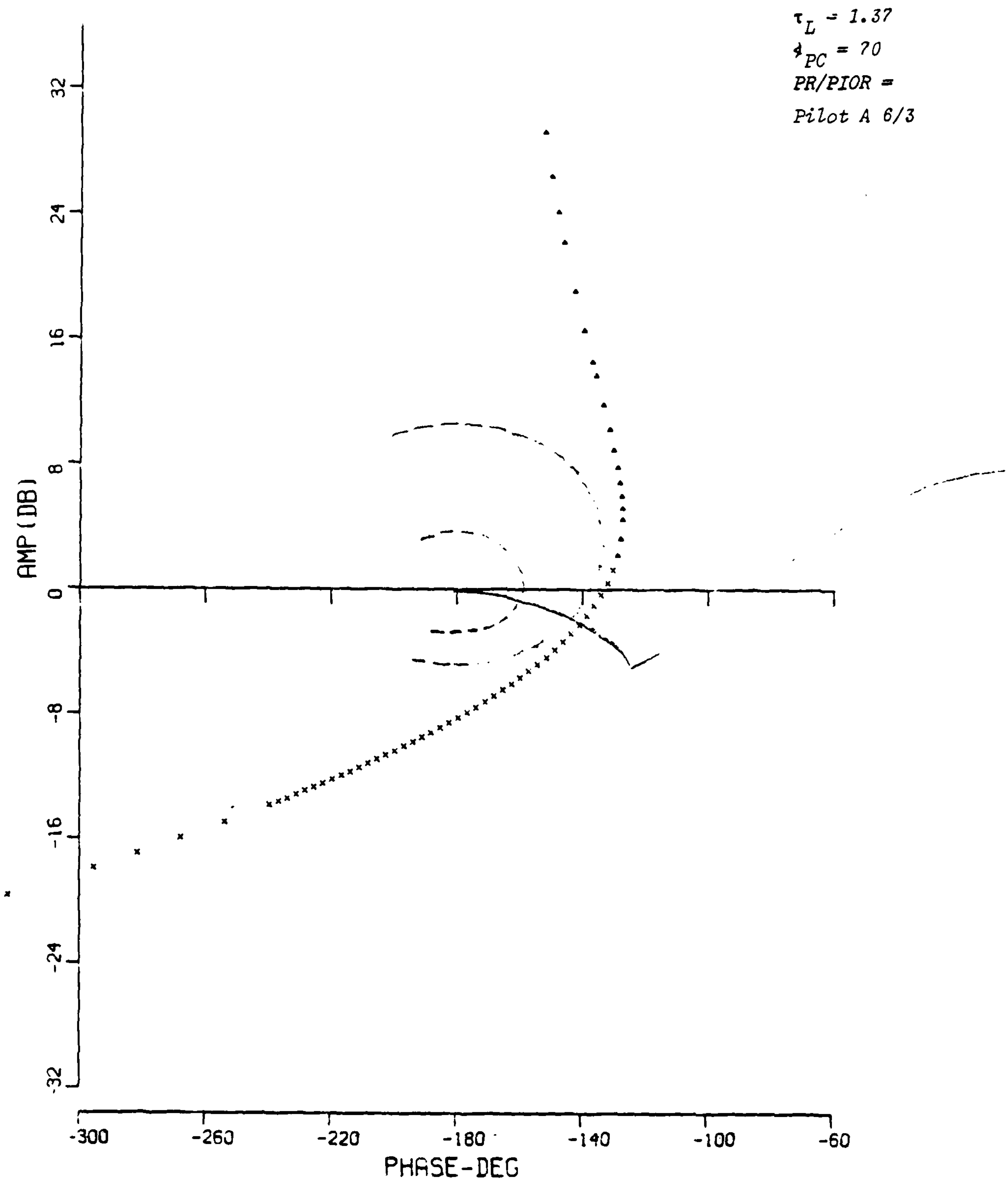
29 APR 1981 PILOT COMP LONG APT - Q FDBK-TQ=1. - KQ=2.75 - HI - DELAY=C



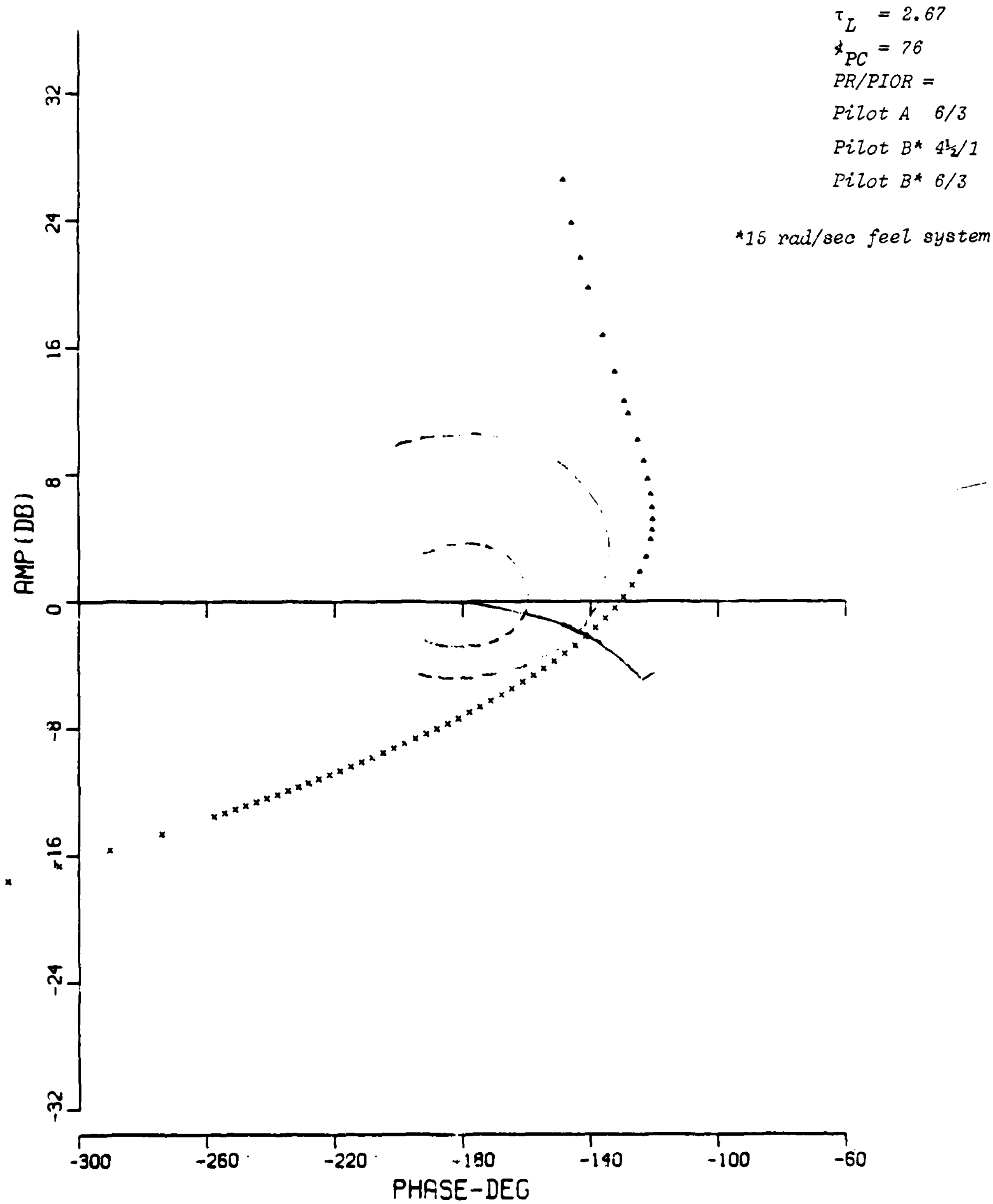
29 APR 1981 PILOT COMP CANARD - ALPHA FDBK - KA=0.00 - UNAUG - DELAY=A



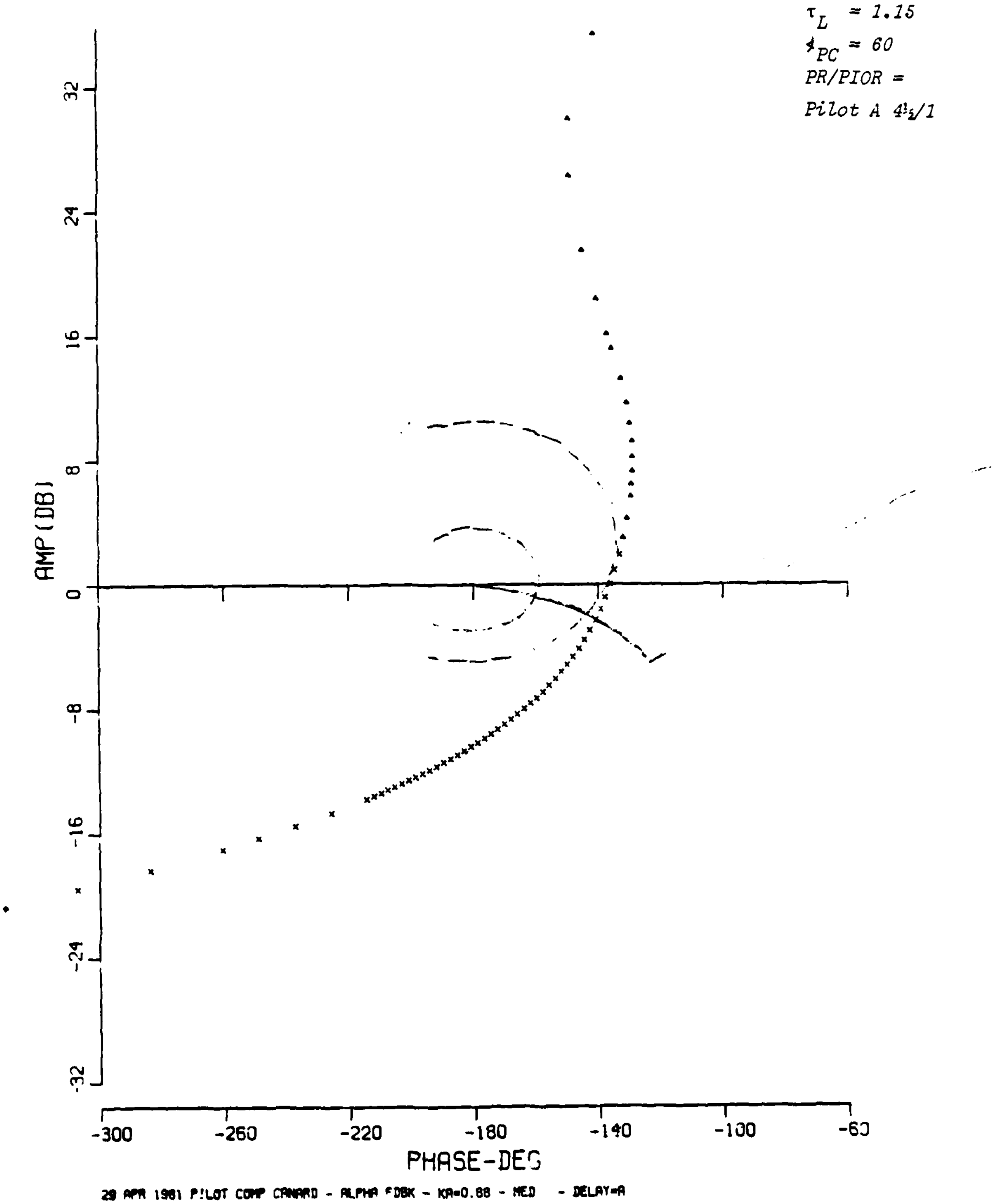
τ_L = 1.23
ϕ_{PC} = 62
PR/PIOR =
Pilot A 3/2
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
1 MAY 1981 PILOT COMP CANARD - ALPHA FDBK - KA=0.62 - LOW - DELAY=A

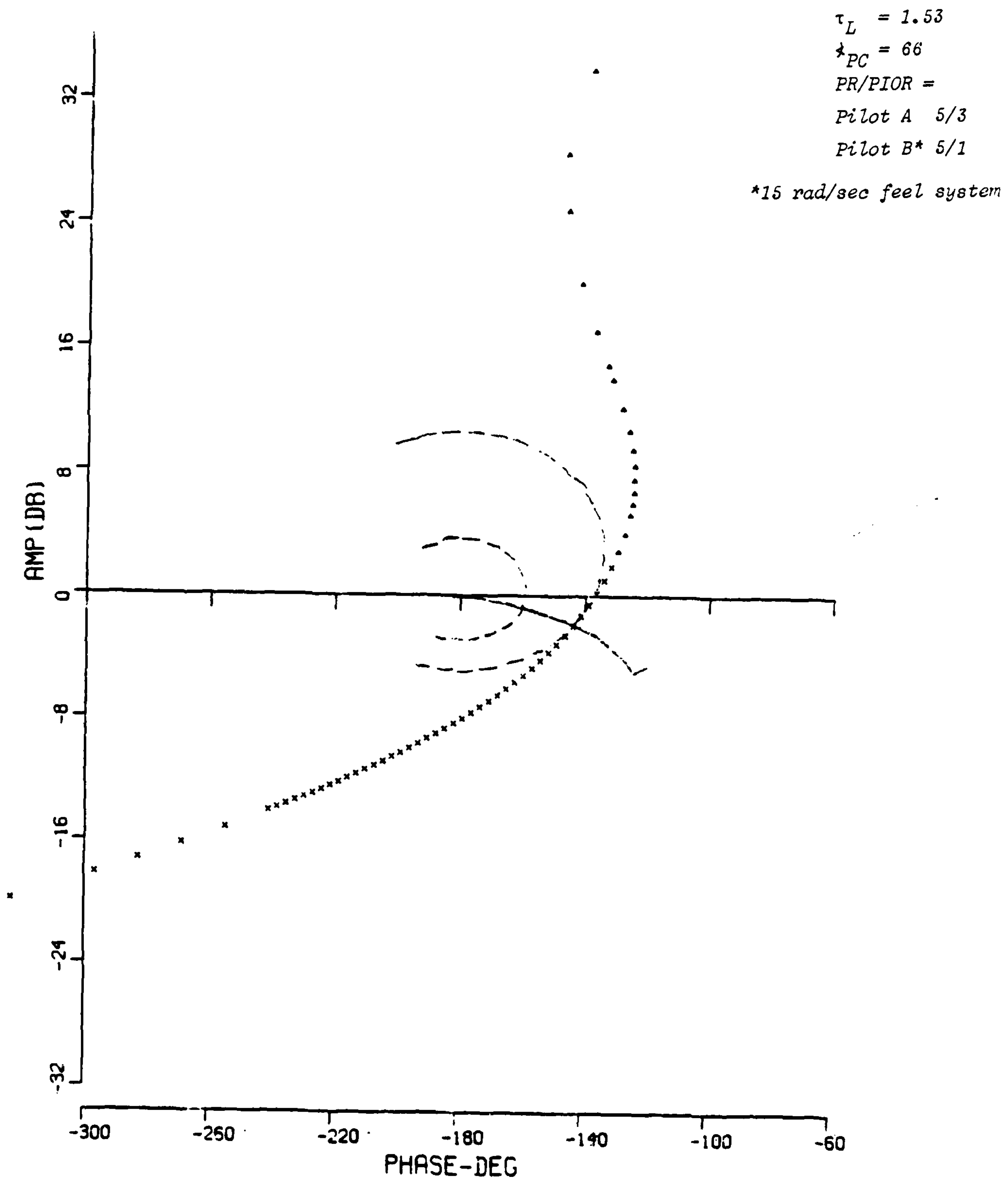


29 APR 1981 PILOT COMP CANARD - ALPHA FDBK - KA=0.62 - LOW - DELAY=8

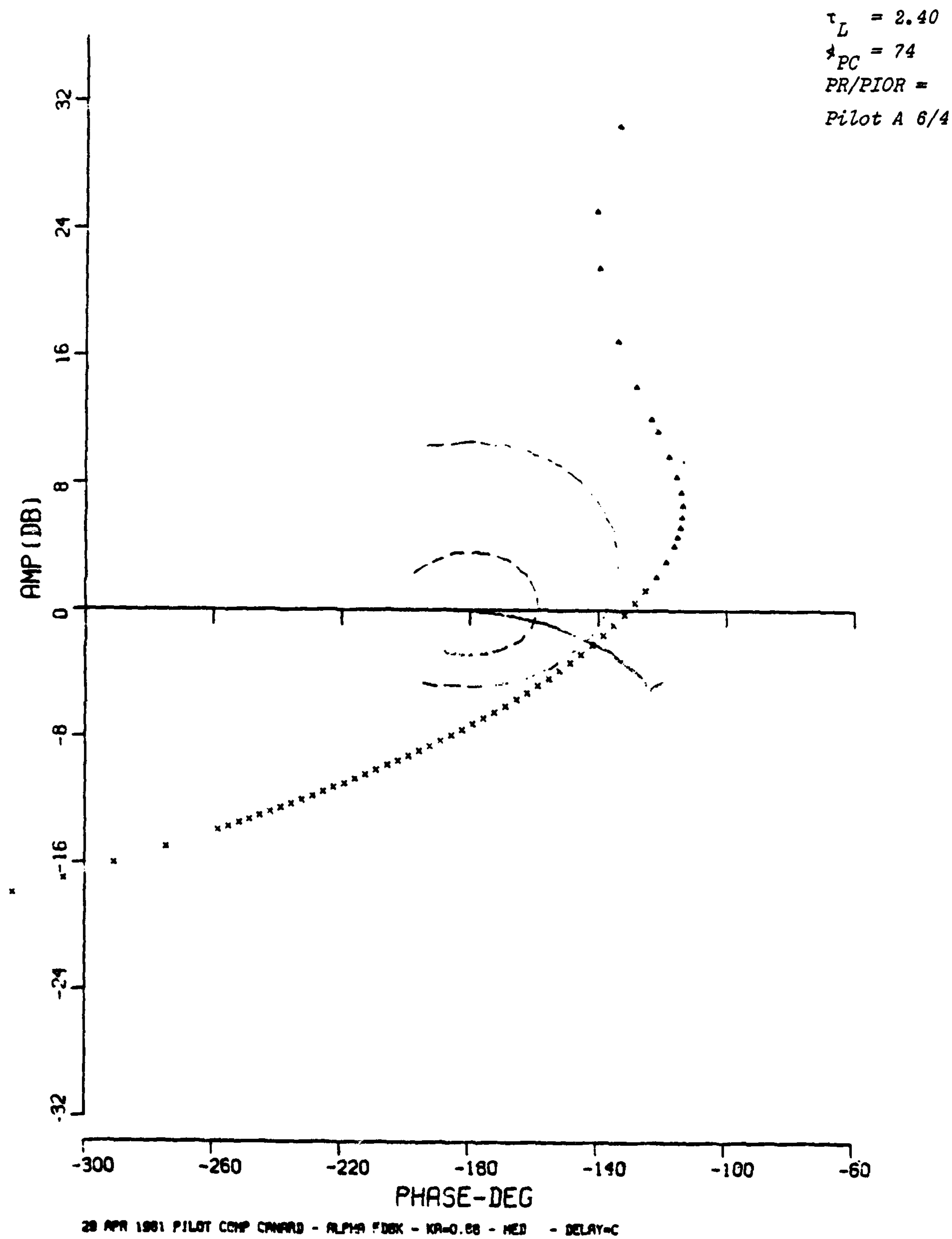


29 APR 1981 PILOT COMP CANARD - ALPHA FDBK - KA=0.62 - LOW - DELAY=C


τ_L = 1.15
ϕ_{PC} = 60
PR/PIOR =
Pilot A 4½/1
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
29 APR 1981 PILOT COMP CANARD - ALPHA FDBK - KA=0.88 - MED - DELAY=A

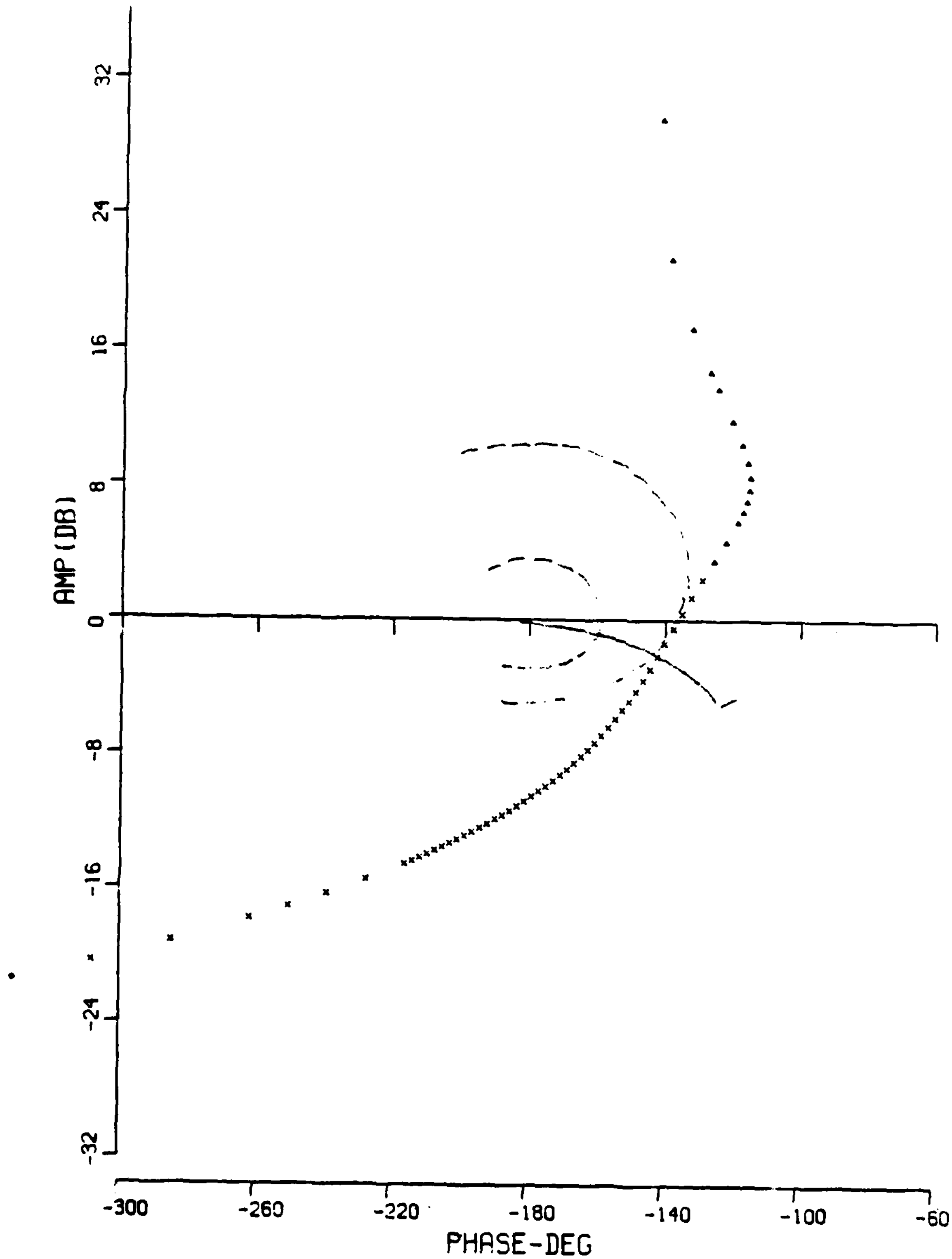


28 APR 1981 PILOT COMP CANARD - ALPHA FDBK - XA=0.28 - MED - DELAY=8

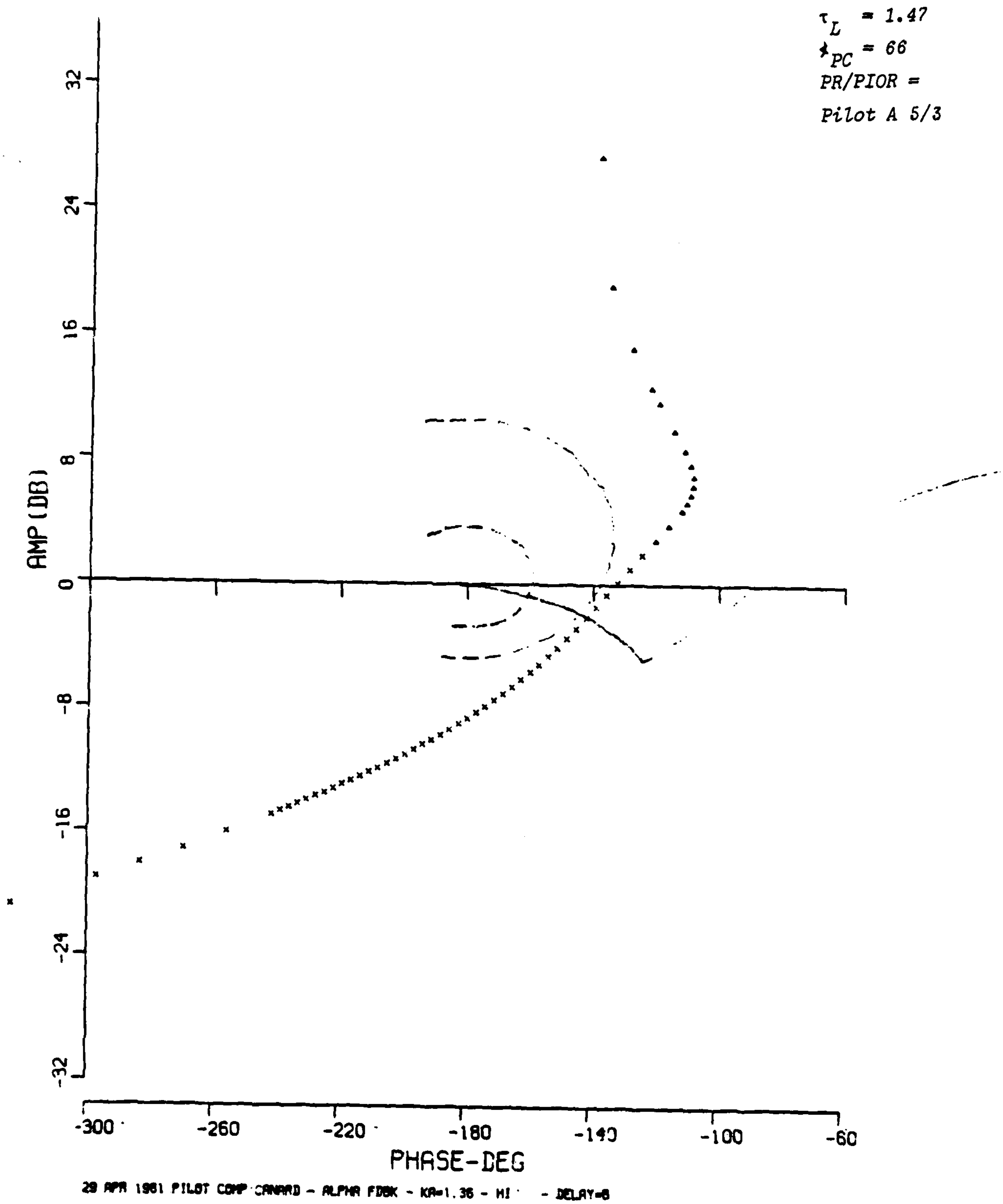


τ_L = 2.40
ϕ_{PC} = 74
PR/PIOR =
Pilot A 6/4
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
28 APR 1981 PILOT COMP CANARD - ALPHA FDBK - KA=0.68 - MED - DELAY=C

$\tau_L = 1.00$
$\phi_{PC} = 56$
PR/PIOR =
Pilot A 4/1
Pilot A 6/3
Pilot A 4/2



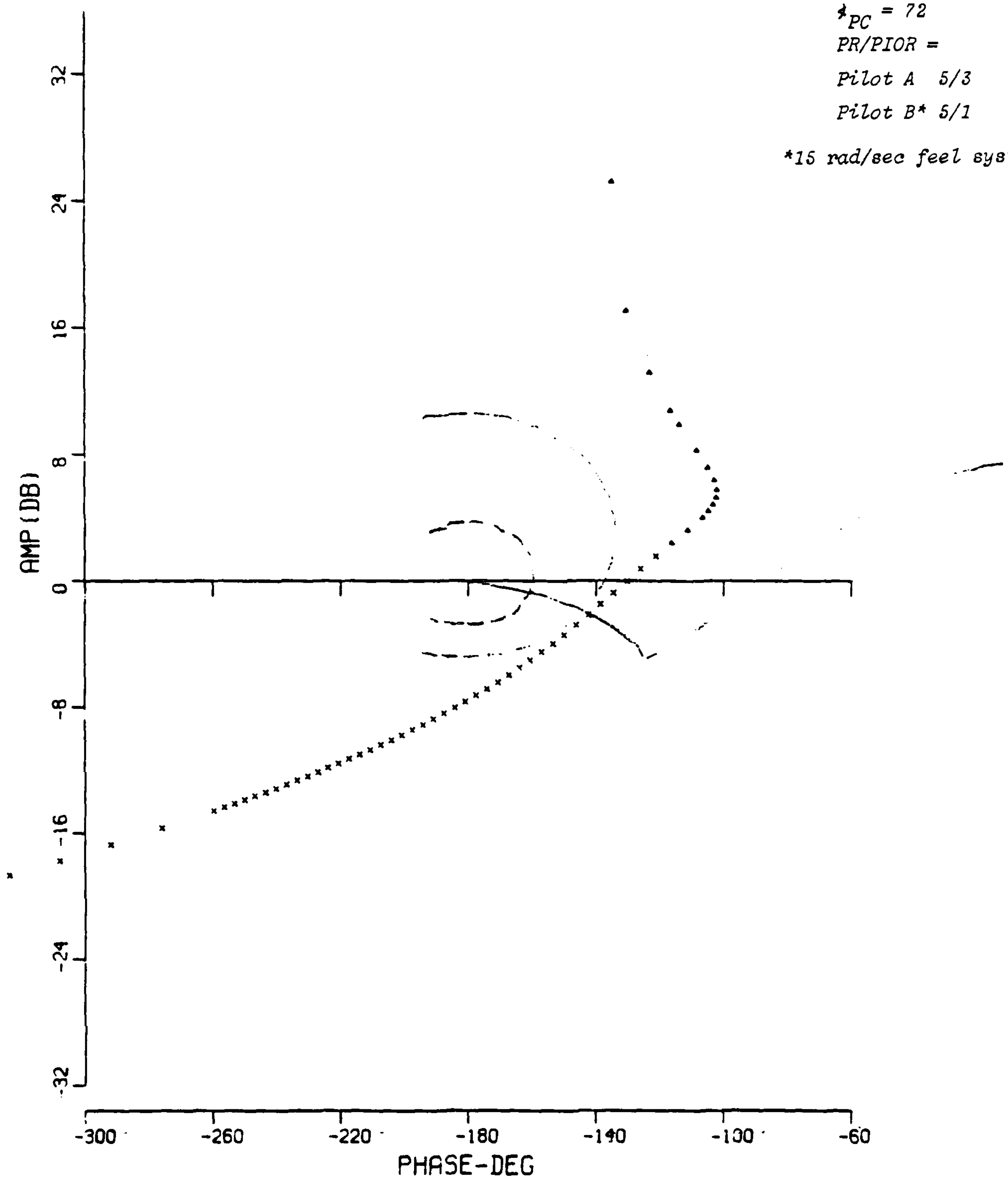
29 APR 1981 PILOT COMP CANARD - ALPHA FDBK - KA=1.36 - HI - DELAY=A



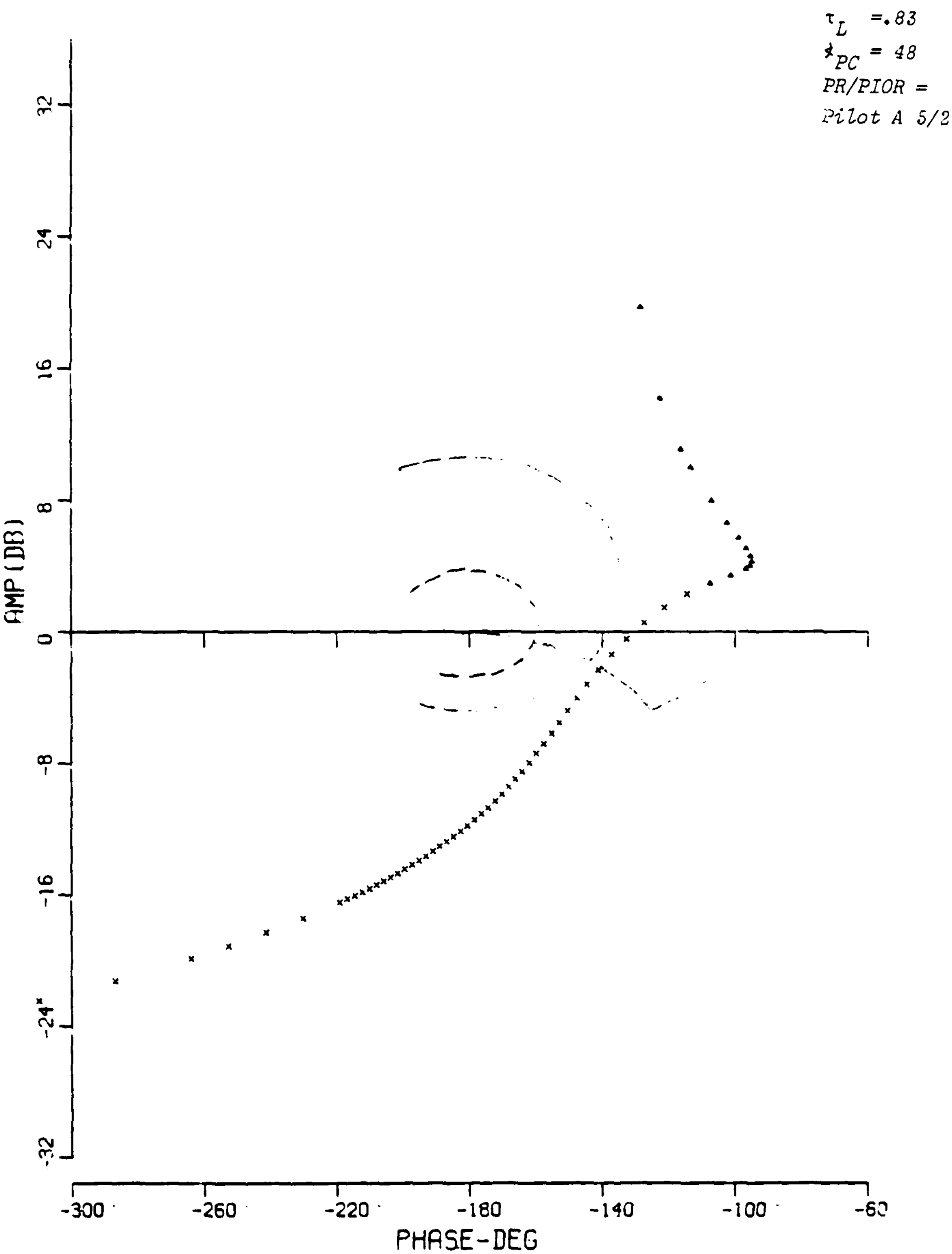
τ_L = 1.47
$\measuredangle_{PC}$ = 66
PR/PIOR =
Pilot A 5/3
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
29 APR 1981 PILOT COMP CANARD - ALPHA FDBK - KA=1.36 - HI - DELAY=8

$\tau_L = 2.00$
$\phi_{PC} = 72$
PR/PIOR =
Pilot A 5/3
Pilot B* 5/1

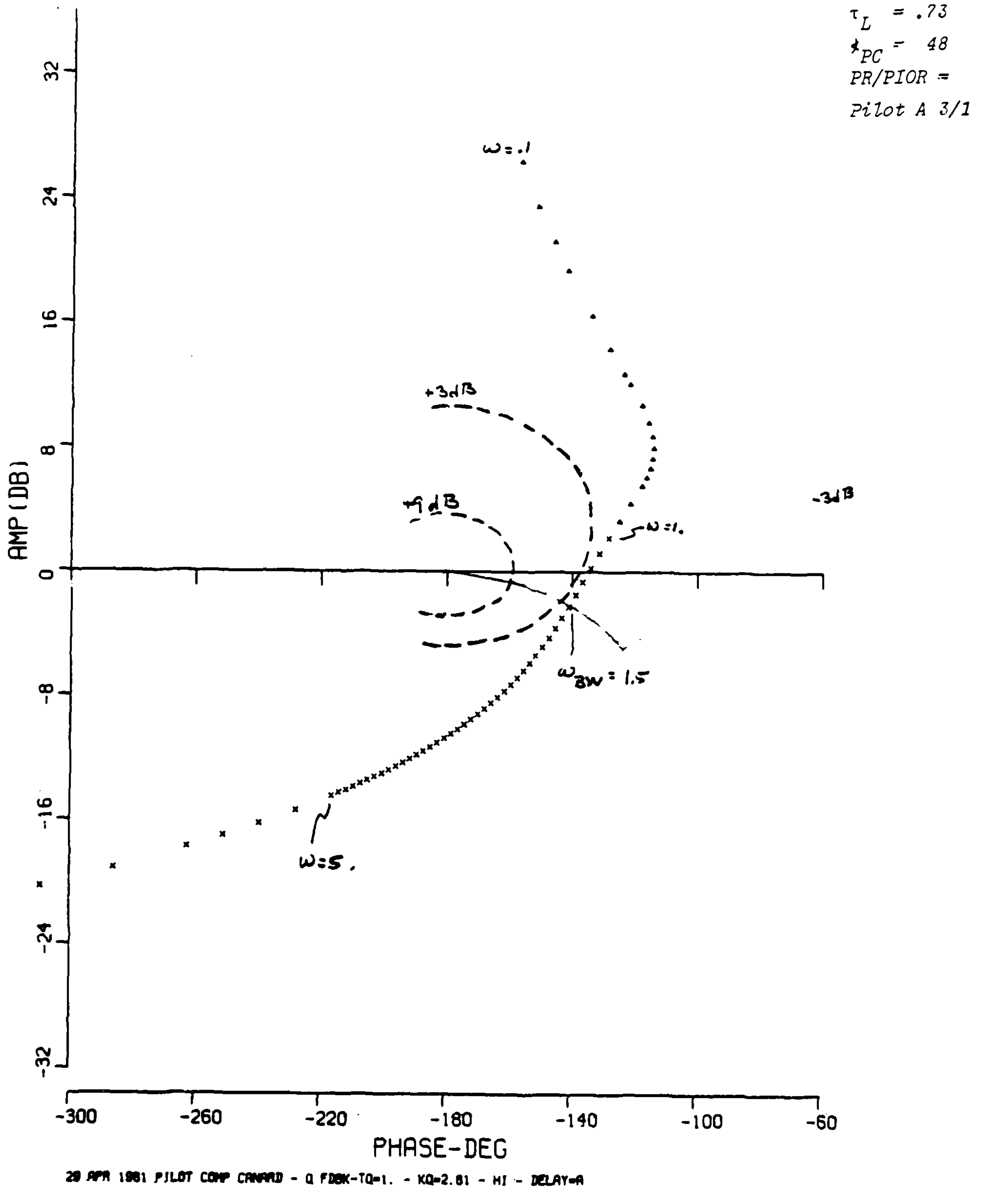
*15 rad/sec feel system



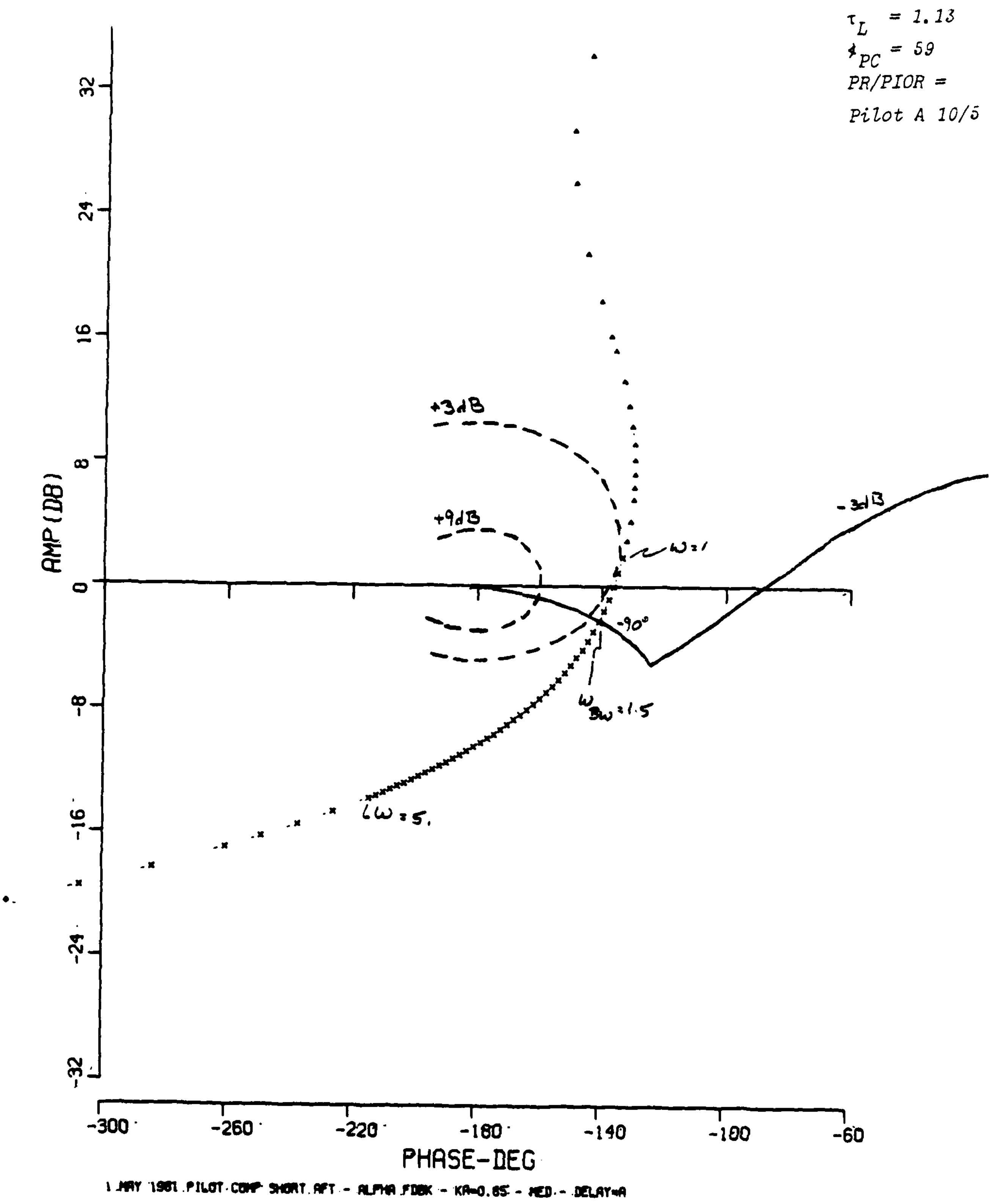
29 APR 1981 PILOT COMP CANARD - ALPHA FDBK - KA=1.36 - HI - DELAY=C



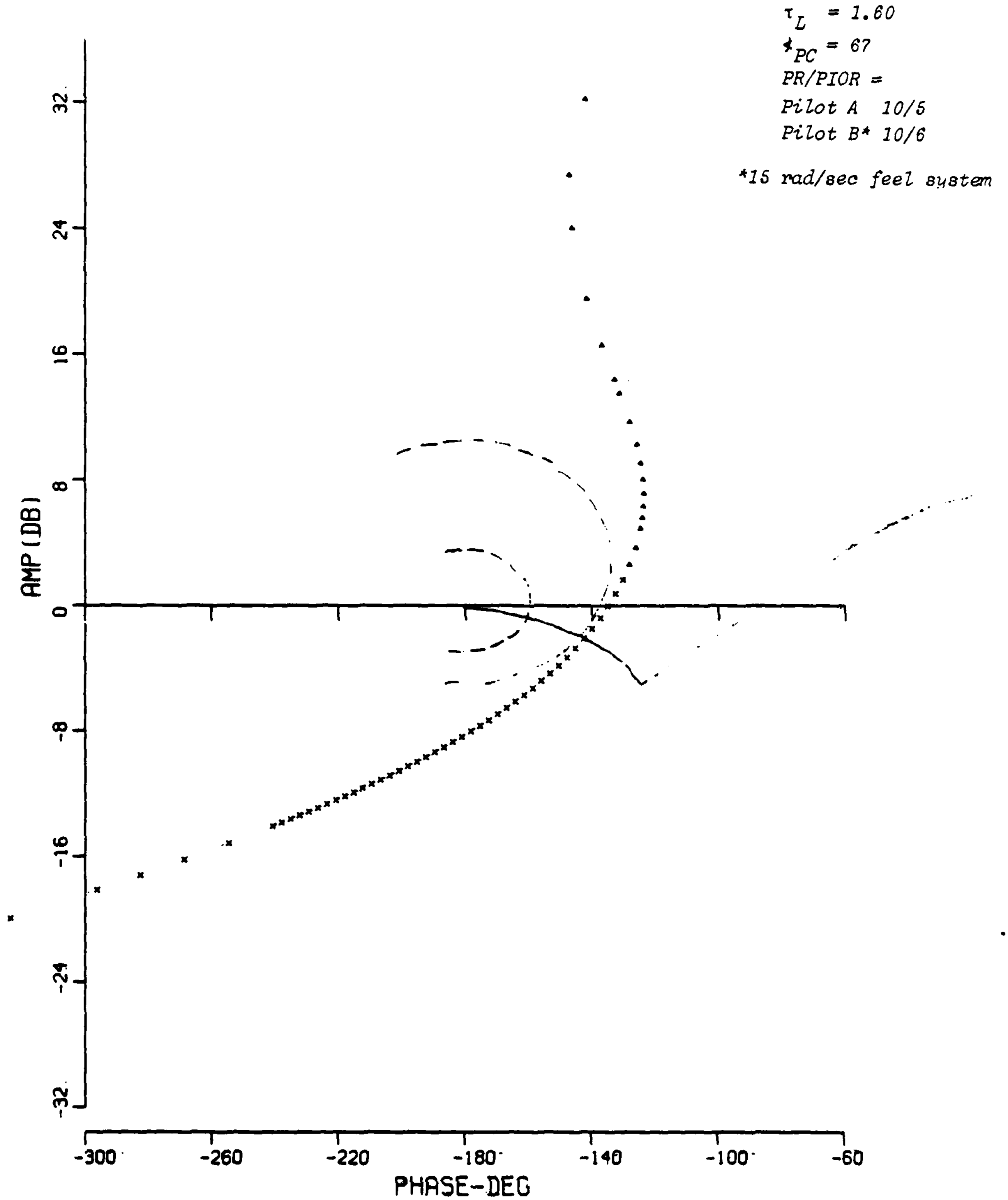
29 APR 1981 PILOT COMP CANARD - ALPHA FDBK - KA=2.30 - EX-HI - DELAY=A



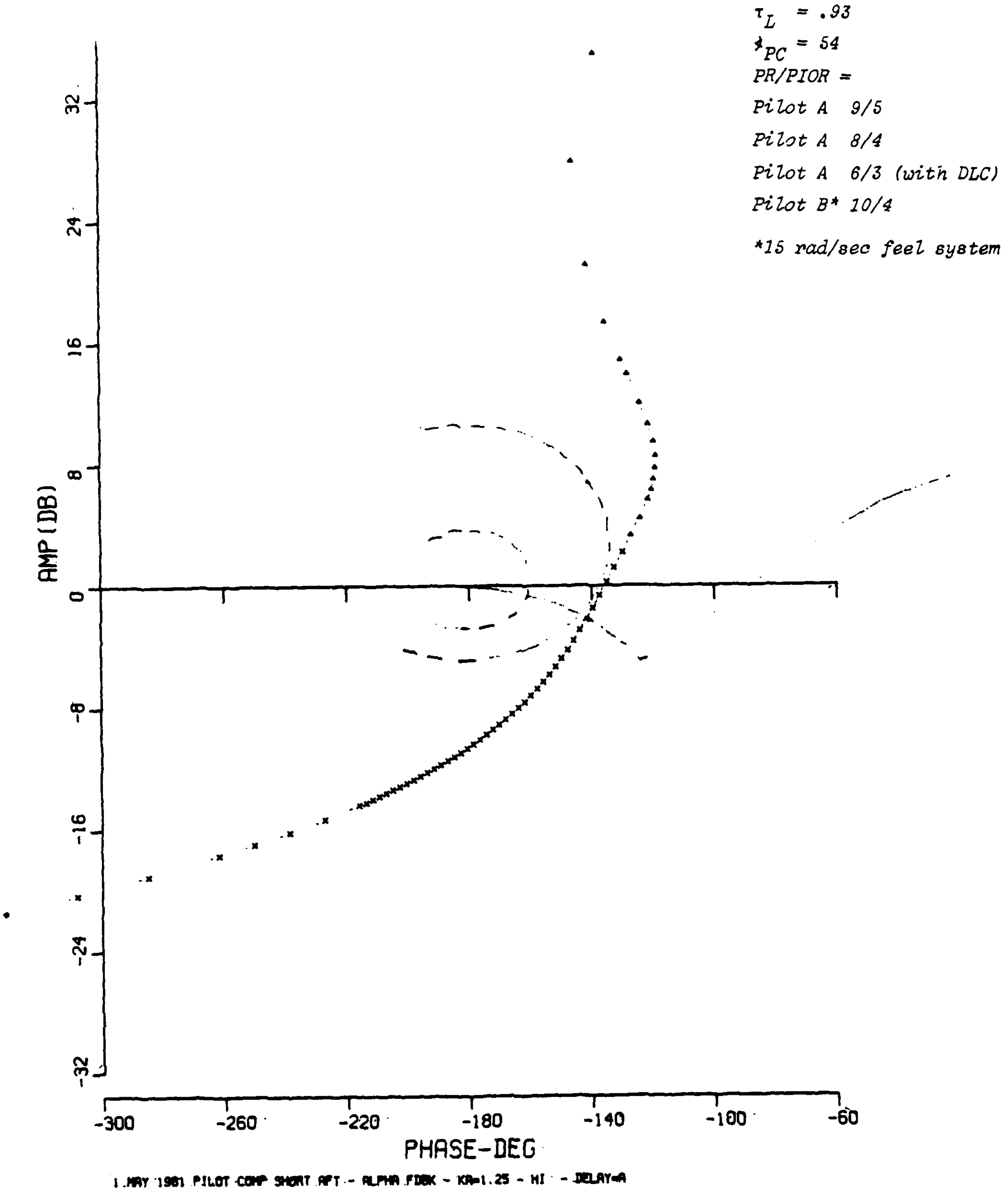
τL = .73
ϕPC = 48
PR/PIOR =
Pilot A 3/1
ω=.1
+3dB
+1dB
-3dB
ω=1.
ωBW = 1.5
ω=5.
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
29 APR 1981 PILOT COMP CANARD - Q FDBK-TQ=1. - KQ=2.81 - HI - DELAY=A



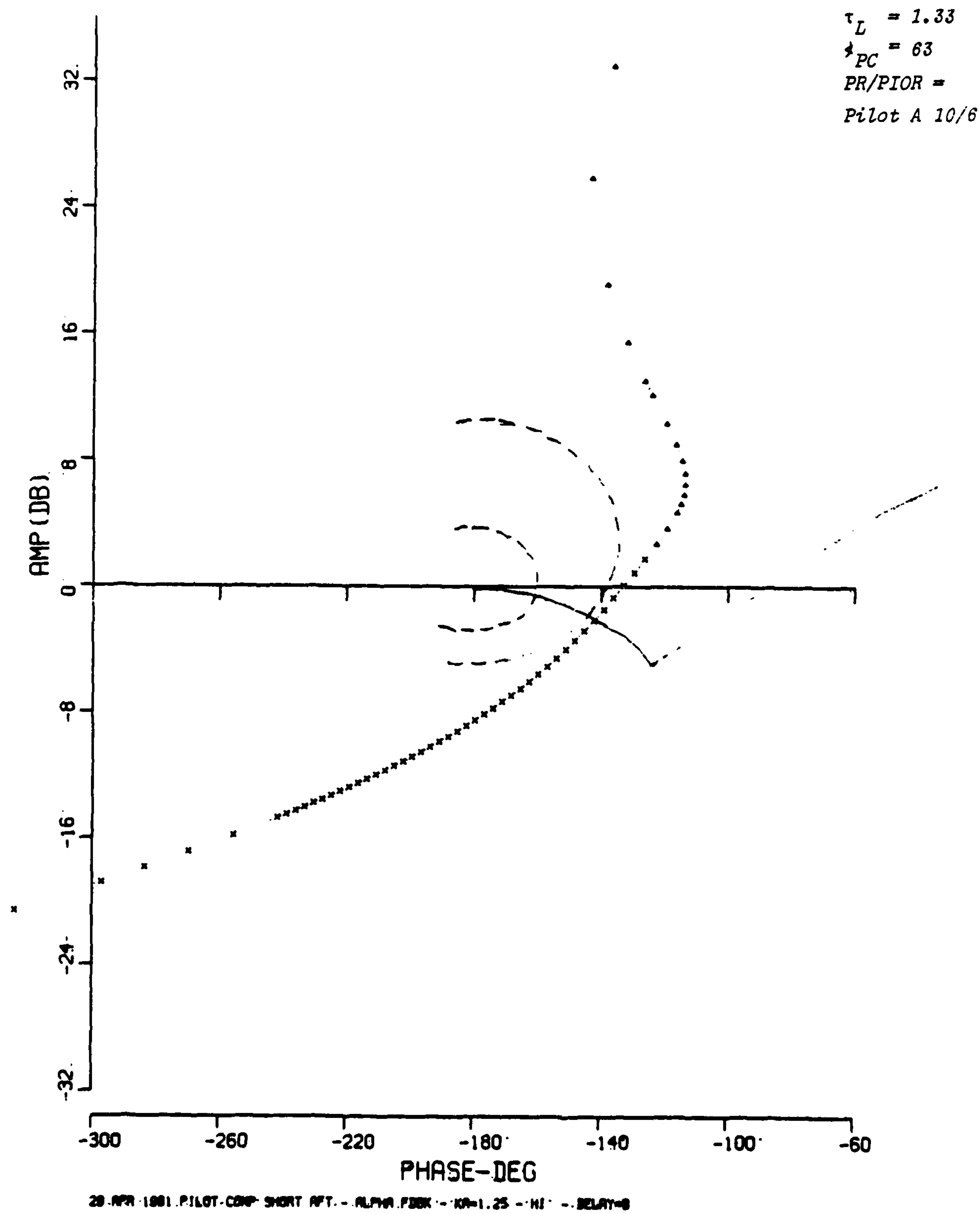
τ_L = 1.13
ϕ_{PC} = 59
PR/PIOR =
Pilot A 10/5
AMP(DB)
32
24
16
8
0
-8
-16
-24
-32
+3dB
+9dB
-3dB
ω=1
-90°
ω_{BW}=1.5
ω=5.
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
1 MAY 1981 PILOT COMP SHORT AFT - ALPHA FDBK - KA=0.65 - MED - DELAY=A



29 APR 1981 PILOT COMP SHORT AFT - ALPHA FDBK - KA=0.85 - MED - DELAY=8

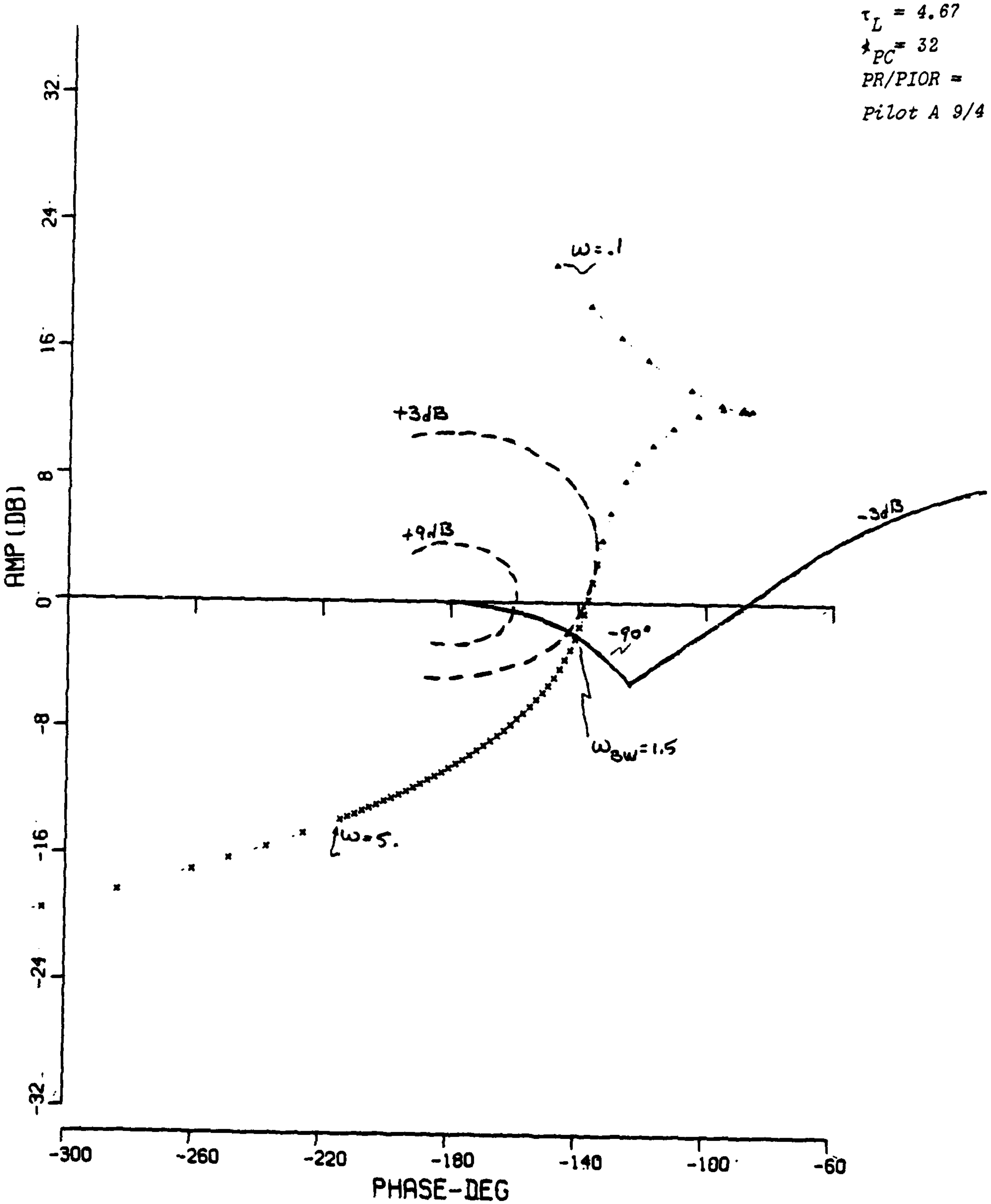


τ_L = .93
$\measuredangle_{PC}$ = 54
PR/PIOR =
Pilot A 9/5
Pilot A 8/4
Pilot A 6/3 (with DLC)
Pilot B* 10/4
*15 rad/sec feel system
AMP(DB)
32
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
1 MAY 1981 PILOT COMP SHORT AFT - ALPHA FDBK - KA=1.25 - HI - DELAY=A

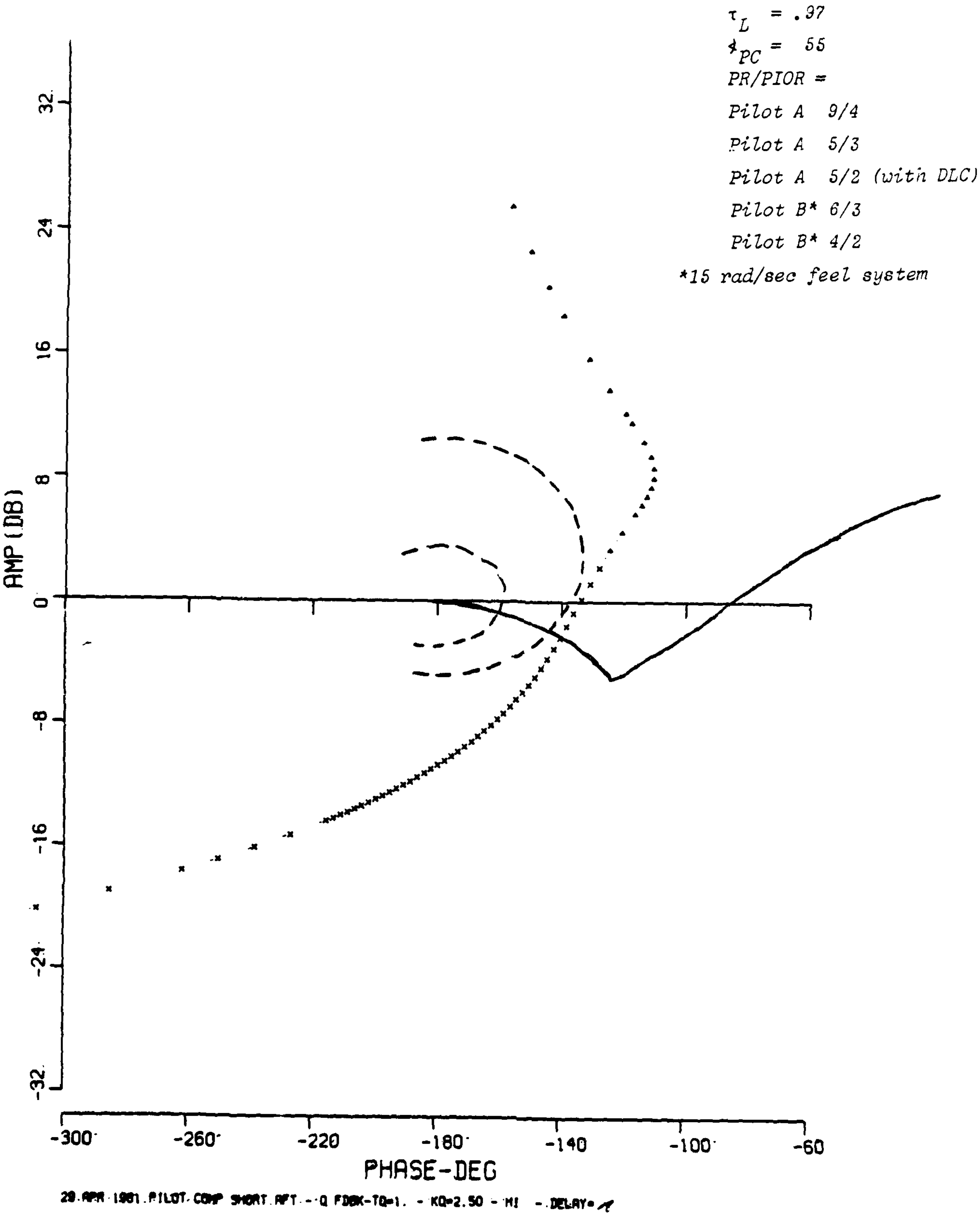


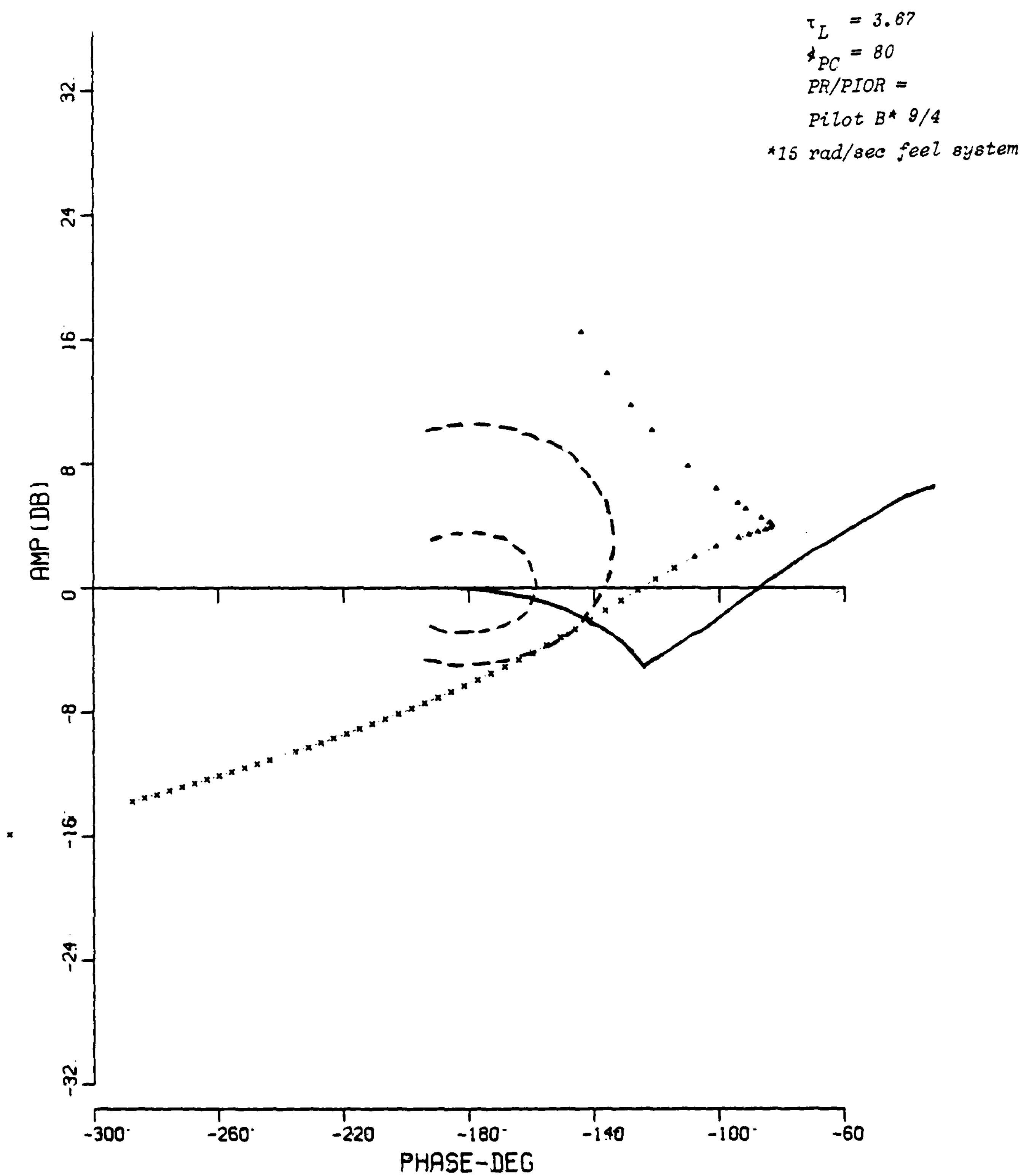
τ_L = 1.33
ϕ_{PC} = 63
PR/PIOR =
Pilot A 10/6
AMP (DB)
32.
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
20 APR 1981 PILOT-COMP SHORT AFT. - ALPHA FDBK - KA=1.25 - HI - DELAY=0

$\tau_L = 4.67$
$\phi_{PC} = 32$
PR/PIOR =
Pilot A 9/4

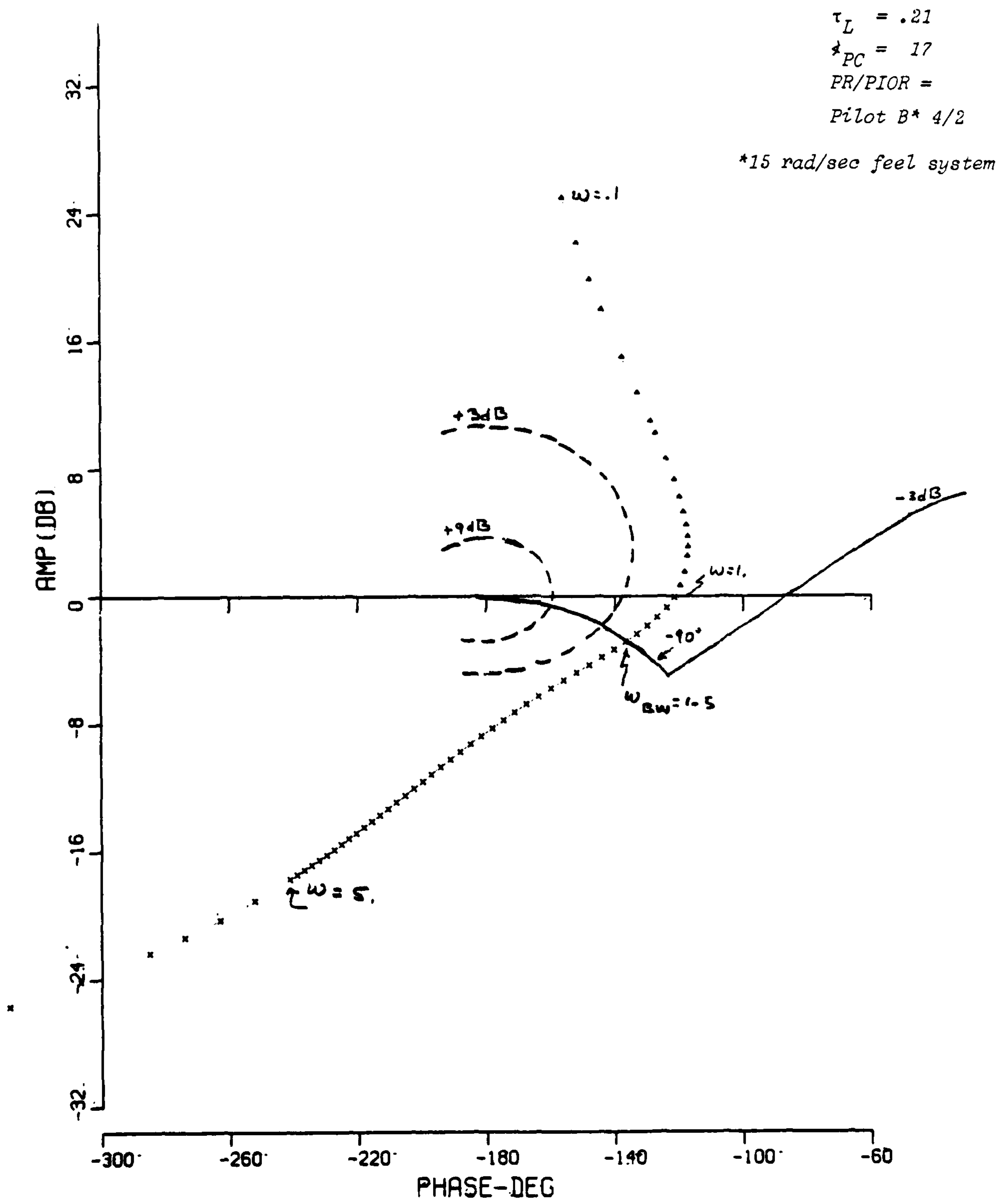


1 MAY 1981 PILOT COMP SHORT AFT - Q FDBK-TQ=1. - KQ=1.05 - MED - DELAY= A


τ_L = .37
ϕ_{PC} = 55
PR/PIOR =
Pilot A 9/4
Pilot A 5/3
Pilot A 5/2 (with DLC)
Pilot B* 6/3
Pilot B* 4/2
*15 rad/sec feel system
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
29 APR 1981 PILOT COMP SHORT APT - - Q FDBK-TQ=1. - KQ=2.50 - HI - - DELAY=



29 APR 1981.PILOT COMP SHORT.AFT. - Q FDBK-TQ=1. - KQ=2.50 - HI - DELAY= .35



29 APR 1981 PILOT COMP SHORT APT --Q FDBK-TQ=.5 - KQ=5.2 - EX-HI - DELAY ≈ .4

Appendix V
ADDITIONAL ANALYSIS RESULTS

This Appendix presents the results of additional analyses which were conducted:

Appendix V-A — Equivalent System Analysis
V-B — Time History Criteria for Pitch Rate Response
V-C — Open-Loop (Aircraft Only) Pitch Attitude Analysis
V-D — Open-Loop (Aircraft Plus Uncompensated Pilot) Pitch Attitude Analysis

None of the criteria which were evaluated correlated very well with the data. All of the criteria show the correct general trend of good ratings tending toward the good area of each criteria plot and bad ratings tending towards the Level 3 directions of parameter values. As mentioned in the body of this report, there are effects in the data that are not handled by the criteria. These are pilot location relative to center of rotation, backside operation and slow thrust response, and benefits and shortcomings of the augmentation systems. Some of these latter effects are gust sensitivity, low frequency and phugoid dynamics, elevator forces required in turns, backside and slow thrust response more critical for α-augmentation, and low q-augmentation is detrimental versus low α-augmentation.

Appendix V-A
EQUIVALENT SYSTEM ANALYSIS

Equivalent lower-order systems were generated for each of the configurations by the Flight Dynamics Laboratory of the Air Force Wright Aeronautical Laboratories. The pitch rate to stick force transfer function was matched with a first-order numerator plus an equivalent time delay, over a second-order denominator. The lower order system, LOS, is of the form:

$$\frac{q}{F_{ES}} = \frac{K\left(s + \frac{1}{T_{\theta_e}}\right)e^{-T_D s}}{s^2+2\zeta_e \omega_{sp_e} s+\omega_{sp_e}^2}$$

The match was done from .25 r/s to 10 r/s for 25 equally spaced frequency values on a log scale. The matching algorithm uses a cost function of

$$\text{COST} = \frac{20}{n}\sum_{\omega_1}^{\omega_n} [(gain_{HOS} - gain_{LOS})^2 + .01745\ (phase_{HOS} - phase_{LOS})^2]$$

where

ω denotes the input frequency gain is in dB
Phase in degrees
n is the number of frequencies.

The computer program did not require using an unstable root in any of the low-order system matches for any of the configurations even though some of the configurations of Appendix I had an unstable root.

The pure time delay effects of .06 seconds for the TIFS model-following or any intentionally introduced pure time delay (.07 records for $T_{1_{pitch}} = C$) would add directly to the equivalent time delay shown in the low-order system matches.

The following is an explanation of the table of equivalent system parameters (Table V-A-1).

The symbol P in the CONF (configuration) column signifies the first-order command prefilter $\left(\frac{1}{.111s+1}\right)$ was included in the higher order system model.

K = numerator coefficient (NUM. COEFF.)

$\frac{1}{T_{\theta_e}}$ = equivalent numerator zero, fixed at the true value of L_α or $\frac{1}{T_{\theta_2}}$ or allowed to run free, $\frac{1}{\text{sec}}$.

T_D = equivalent time delay $\left(\begin{array}{c}\text{EQUIV}\\ \text{TIME DELAY}\end{array}\right)$, sec.

(This does <u>not</u> include any pure time delay effects such as the TIFS model-following delay of .06 seconds or any intentionally introduced pure time delay).

ζ_e = equivalent damping ratio

ω_{sp_e} = equivalent short period natural frequency, rad/sec

The upward pointing arrows beside some of the $\frac{1}{T_{\theta_e}}$ free values mean that when the program was stopped, the value of $\frac{1}{T_{\theta_e}}$ was still being raised by the program (usually after about 2500 iterations). In all cases, the fit was excellent as shown by the relatively low value of the COST function.

For $n_z/\alpha = 2$ for the long aft tail configuration, the pitch rate numerator did not reduce to two real roots, but instead, was two complex roots; so only $\frac{1}{T_{\theta_e}}$ free could be matched for this configuration.

The equivalent time delay matches for the 25 r/s feel system, the 15 r/s feel system, and a 20 r/s first-order actuator are:

25 r/s feel = .058 sec time delay, COST = .02

15 r/s feel = .100 sec time delay, COST = .75

20 r/s actuator = .048 sec time delay, COST = 1.75

Inspection of many of the configurations without the command prefilter (which adds about .09 seconds of equivalent time delay when included) shows that the equivalent time delay for these configurations is essentially due to the feel system and actuator dynamics.

When two negative numbers are listed vertically in the ζ_e-ω_{sp_e} columns, the equivalent system denominator for these configurations factors to two real roots at the values shown.

A comparison of the equivalent system parameters ω_{sp_e} and T_D to MIL-F-8785C criteria for short-period frequency requirements and allowable response delay is shown in Figures V-A-1 through V-A-3, along with the pilot ratings received. Only points obtained with $\frac{1}{T_{\theta_e}}$ fixed are presented.

The flying quality levels for equivalent time delay and short period frequency are combined in Figures V-A-4 through V-A-7, where the pilot ratings for the configurations flown are called out.

TABLE V-A-1. EQUIVALENT SYSTEM PARAMETERS

CONF.		NUM. COEFF.	$\frac{1}{T_{\theta_e}}$	FIXED?	EQUIV. TIME DELAY *	ζ_e	ω_{sp_e}	COST
		LONG AFT TAIL α-FEEDBACK 25 R/S FEEL						
Unaug	$K_\alpha = 0$	.1092	.5149	Y	.1028	- .05942 - .9440		4.57
	$K_\alpha = 0$	.1116	.7727	N	.1059	- .08921 -1.291		3.17
	$K_\alpha = 0, P$	.09515	.5149	Y	.1906	- .08841 - .7701		17.49
	$K_\alpha = 0, P$	.09515	.5145	N	.1906	- .08836 - .7696		17.49
Low	$K_\alpha = .61$	.1126	.5149	Y	.1033	- .3453 - .7160		1.08
	$K_\alpha = .61$	.1126	.5283	N	.1034	- .3501 - .7255		1.08
	$K_\alpha = .61P$	.09835	.5149	Y	.1911	.938	.488	19.13
	$K_\alpha = .61P$	.01116	86.14†	N	.111	- .5068 -8.646		1.95
Med	$K_\alpha = .9$	.114	.5149	Y	.104	.924	.59	2.22
	$K_\alpha = .9$	.0995	6.965†	N	.0916	- .6965 -5.572		1.13
	$K_\alpha = .9P$	.0996	.5149	Y	.191	.822	.574	22.41
	$K_\alpha = .9P$	.0566	11.06†	N	.145	- .7194 -4.938		2.34
High	$K_\alpha = 1.35$	.1158	.5149	Y	.104	.786	.719	5.78
	$K_\alpha = 1.35$	.1115	1.085	N	.099	.762	.984	3.55

*Does not include model-following time delays.

TABLE V-A-1. EQUIVALENT SYSTEM PARAMETERS (CONT'D)

CONF.		NUM. COEFF.	$\frac{1}{T_{\theta_e}}$	FIXED?	EQUIV. TIME DELAY *	ζ_e	ω_{sp_e}	COST
High	K_α=1.35P	.1012	.5149	Y	.192	.705	.696	28.55
	K_α=1.35P	.0657	6.865	N	.149	-1.392 -2.390		10.25
Ex-Hi	K_α=2.1	.1178	.5149	Y	.105	.65	.908	12.56
	K_α=2.1	.1119	.910	N	.0983	.589	1.11	7.03
LONG AFT TAIL $N_z/\alpha = 3$								
High	K_α=1.45	.1172	.3362	Y	.106	.742	.677	9.46
	K_α=1.45	.1125	.709	N	.100	.656	.889	4.47
LONG AFT TAIL $N_z/\alpha = 2$								
High	K_α=1.6	.1133	.433	N	.100	.553	.836	5.1
LONG AFT TAIL, T_q = 1, q-FEEDBACK 25 R/S FEEL								
Low	K_q=.6	.2665	.5153	Y	.104	.381	.380	3.42
	K_q=.6	.2656	.5347	N	.103	.388	.382	3.36
	K_q=.6P	.2423	.5153	Y	.196	.341	.380	21.75
	K_q=.6P	.2344	.689	N	.191	.396	.401	17.85
Med	K_q=1.3	.5884	.5152	Y	.103	.538	.554	1.49
	K_q=1.3	.590	.497	N	.104	.536	.548	1.47
	K_q=1.3P	.5263	.5152	Y	.193	.482	.545	18.63
	K_q=1.3P	.5119	.7235	N	.190	.512	.604	16.44

*Does not include model-following time delays.

TABLE V-A-1. EQUIVALENT SYSTEM PARAMETERS (CONT'D)

	CONF.	NUM. COEFF.	$\frac{1}{T_{\theta_e}}$	FIXED?	EQUIV. TIME DELAY *	ζ_e	ω_{sp_e}	COST
High	K_q=2.75	1.289	.5147	Y	.104	.788	.816	.96
	K_q=2.75	1.292	.4792	N	.105	.797	.793	.93
	K_q=2.75P	1.116	.5147	Y	.191	.703	.783	15.69
	K_q=2.75P	1.070	1.015	N	.185	.671	1.02	13.65
			CANARD α-FEEDBACK 25 R/S FEEL					
Unaug	K_α=0	.1121	.5174	Y	.103	- .08586 - .9940		3.93
	K_α=0	.1141	.740	N	.106	- .1173 -1.290		2.89
Low	K_α=.62	.115	.5174	Y	.103	- .3579 - .7189		1.08
	K_α=.62	.115	.5157	N	.103	- .3573 - .7178		1.08
	K_α=.62P	.100	.5174	Y	.191	.934	.497	19.09
	K_α=.62P	.0149	65.43†	N	.114	- .5237 -8.537		1.84
Med	K_α=.88	.11[illegible]2	.5174	Y	.103	.928	.580	2.11
	K_α=.88	.0964	9.398†	N	.089	- .6632 -7.231		1.01
	K_α=.88P	.1016	.5174	Y	.191	.825	.565	22.18
	K_α=.88P	.00987	88.23†	N	.100	- .6645 -6.944		1.03

*Does not include model-following time delays.

TABLE V-A-1. EQUIVALENT SYSTEM PARAMETERS (CONT'D)

CONF.		NUM. COEFF.	$\frac{1}{T_{\theta_e}}$	FIXED?	EQUIV. TIME DELAY *	ζ_e	ω_{sp_e}	COST
High	K_α=1.36	.1181	.5174	Y	.104	.763	.704	6.26
	K_α=1.36	.1139	1.041	N	.099	.747	.941	4.04
	K_α=1.36R	.1035	.5174	Y	.192	.685	.682	29.45
	K_α=1.36R	.07185	5.659	N	.154	.992	1.67	11.77
Ex-Hi	K_α=2.3	.1205	.5174	Y	.105	.570	.919	16.59
	K_α=2.3	.1141	.873	N	.097	.520	1.088	9.66
CANARD q-FEEDBACK, T_q = 1, 25 R/S FEEL								
High	K_q=2.81	.1683	.5177	Y	.104	.838	.832	1.03
	K_q=2.81	.1690	.442	N	.104	.863	.780	.92
SHORT AFT TAIL α-FEEDBACK 25 R/S FEEL								
Unaug	K_α=0	.1068	.5158	Y	.103	- .03607 - .9061		5.18
	K_α=0	.1094	.8069	N	.106	- .06391 -1.301		3.44
	K_α=0P	.09322	.5158	Y	.191	- .06339 - .7434		17.96
	K_α=0P	.09332	.5411	N	.191	- .06601 - .7719		17.94
Med	K_α=.85	.1117	.5158	Y	.104	.949	.578	1.92
	K_α=.85	.08747	12.29†	N	.087	- .6632 -9.050		.65

*Does not include model-following time delays.

TABLE V-A-1. EQUIVALENT SYSTEM PARAMETERS (CONT'D)

CONF.		NUM. COEFF.	$\frac{1}{T_{\theta_e}}$	FIXED?	EQUIV. TIME DELAY*	ζ_e	ω_{sp_e}	COST
Med	K_α=.85P	.09761	.5158	Y	.191	.843	.563	21.76
	K_α=.85P	.02174	38.00	N	.114	- .6666 -6.924		.82
High	K_α=1.25	.1134	.5158	Y	.104	.826	.705	4.69
	K_α=1.25	.1093	1.205	N	.100	.808	1.020	2.81
	K_α=1.25P	.09901	.5158	Y	.192	.740	.682	26.6
	K_α=1.25P	.05039	11.58	N	.136	-1.089 -3.939		7.01
SHORT AFT TAIL q-FEEDBACK, T_q= 1, 25 R/S FEEL								
Med	K_q=1.05	.05808	.5156	Y	.104	.442	.499	1.84
	K_q=1.05	.05798	.5275	N	.104	.444	.502	1.82
	K_q=1.05P	.05242	.5156	Y	.195	.396	.493	20.73
	K_q=1.05P	.05070	.7174	N	.191	.434	.537	17.27
High	K_q=2.5	.1430	.5157	Y	.105	.713	.773	.98
	K_q=2.5	.1431	.5093	N	.105	.714	.770	.98
	K_q=2.5P	.1250	.5157	Y	.192	.639	.746	17.10
	K_q=2.5P	.1199	.9327	N	.186	.623	.929	14.52
Ex-Hi T_q=.5	K_q=5.2	.3695	.5158	Y	.124	.936	1.32	17.30
	K_q=5.2	.3126	1.927	N	.105	.618	2.17	1.09

*Does not include model-following time delays.

TABLE V-A-1. EQUIVALENT SYSTEM PARAMETERS (CONT'D)

(The following configurations were flown by Pilot B with 15 r/s pitch feel system)

CONF.		NUM. COEFF.	$\frac{1}{T_{\theta_e}}$	FIXED?	EQUIV. TIME DELAY *	ζ_e	ω_{sp_e}	COST
			LONG AFT TAIL α-FEEDBACK, 15 R/S FEEL					
High	K_α=1.35P	.1004	.5149	Y	.234	.701	.696	34.38
High	K_α=1.35P	.03028	21.77	N	.152	-1.120 -4.251		11.71
			LONG AFT TAIL $N_z/\alpha = 3$					
High	K_α=1.45	.1162	.3362	Y	.148	.737	.677	11.81
High	K_α=1.45	.1113	.7268	N	.142	.650	.896	6.51
			LONG AFT TAIL $N_z/\alpha = 2$					
High	K_α=1.6	.1123	.4361	N	.142	.548	.838	7.25
			LONG AFT TAIL q-FEEDBACK, 15 R/S FEEL					
High	K_q=2.75	1.276	.5147	Y	.146	.782	.815	2.50
High	K_q=2.75	1.278	.4874	N	.146	.789	.798	2.48
			CANARD α-FEEDBACK, 15 R/S FEEL					
Low	K_α=.62P	.09954	.5174	Y	.233	.927	.498	24.41
Low	K_α=.62P	.007637	121.2†	N	.145	- .5302 -8.084		2.97
Med	K_α=.88P	.1007	.5174	Y	.233	.819	.565	27.66
Med	K_α=.88P	.009009	92.14†	N	.138	- .6750 -6.568		1.82

*Does not include model-following time delays.

TABLE V-A-1. EQUIVALENT SYSTEM PARAMETERS (CONCLUDED)

(The following configurations were flown by Pilot B with 15 r/s pitch, feel system)

CONF.		NUM. COEFF.	$\frac{1}{T_{\theta_e}}$	FIXED?	EQUIV. TIME DELAY *	ζ_e	ω_{sp_e}	COST
High	K_α=1.36	.1170	.5174	Y	.146	.757	.704	8.52
High	K_α=1.36	.1123	1.105	N	.140	.745	.964	5.97
High	K_α=1.36P	.1026	.5174	Y	.234	.681	.682	35.37
High	K_α=1.36P	.04302	14.19	N	.165	-1.098 -3.724		13.62
SHORT AFT TAIL α-FEEDBACK, 15 R/S FEEL								
Med	K_α=.85P	.09674	.5158	Y	.233	.836	.563	27.22
Med	K_α=.85P	.008055	100.5†	N	.139	- .6733 -6.755		1.56
High	K_α=1.25	.1124	.5158	Y	.146	.819	.705	6.86
High	K_α=1.25	.1075	1.338	N	.141	.811	1.066	4.61
SHORT AFT TAIL, q-FEEDBACK, T_q = 1, 15 R/S FEEL								
High	K_q=2.5	.1417	.5157	Y	.146	.708	.773	2.54
High	K_q=2.5	.1417	.5169	N	.146	.708	.773	2.54
High	K_q=2.5P	.1239	.5157	Y	.234	.634	.746	22.20
High	K_q=2.5P	.1183	.9858	N	.228	.621	.947	19.30
Ex-Hi T_q=.5	K_q=5.2	.3647	.5158	Y	.166	.927	1.315	20.53
Ex-Hi T_q=.5	K_q=5.2	.3032	2.093	N	.145	.605	2.227	2.58

*Does not include model-following time delays.

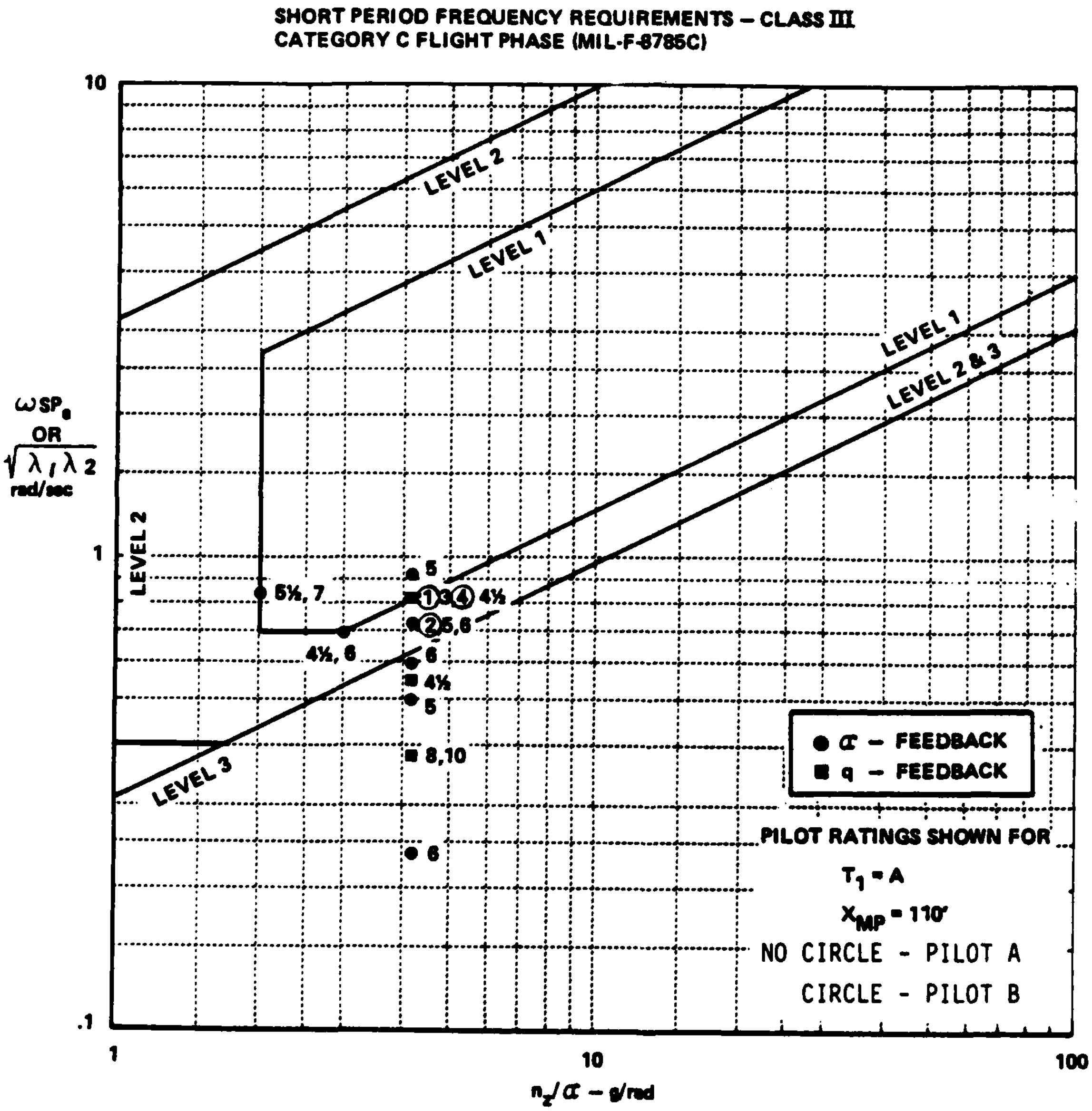


Figure V-A-1. LONG AFT TAIL CONFIGURATIONS VS ω_{SP_e} REQUIREMENTS

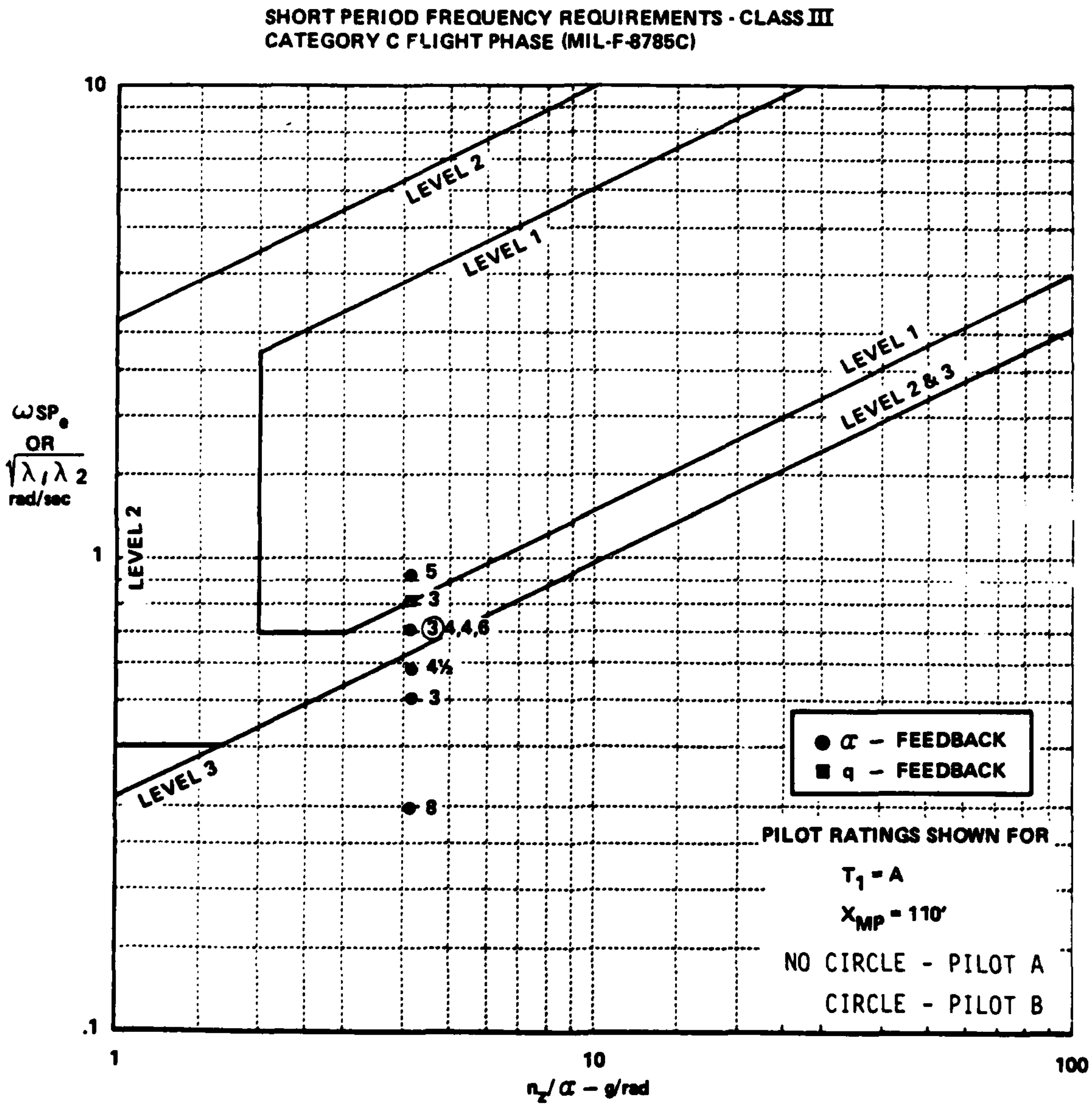


Figure V-A-2. CANARD CONFIGURATIONS VS ω_{SP_e} REQUIREMENTS

SHORT PERIOD FREQUENCY REQUIREMENTS - CLASS III
CATEGORY C FLIGHT PHASE (MIL-F-8785C)

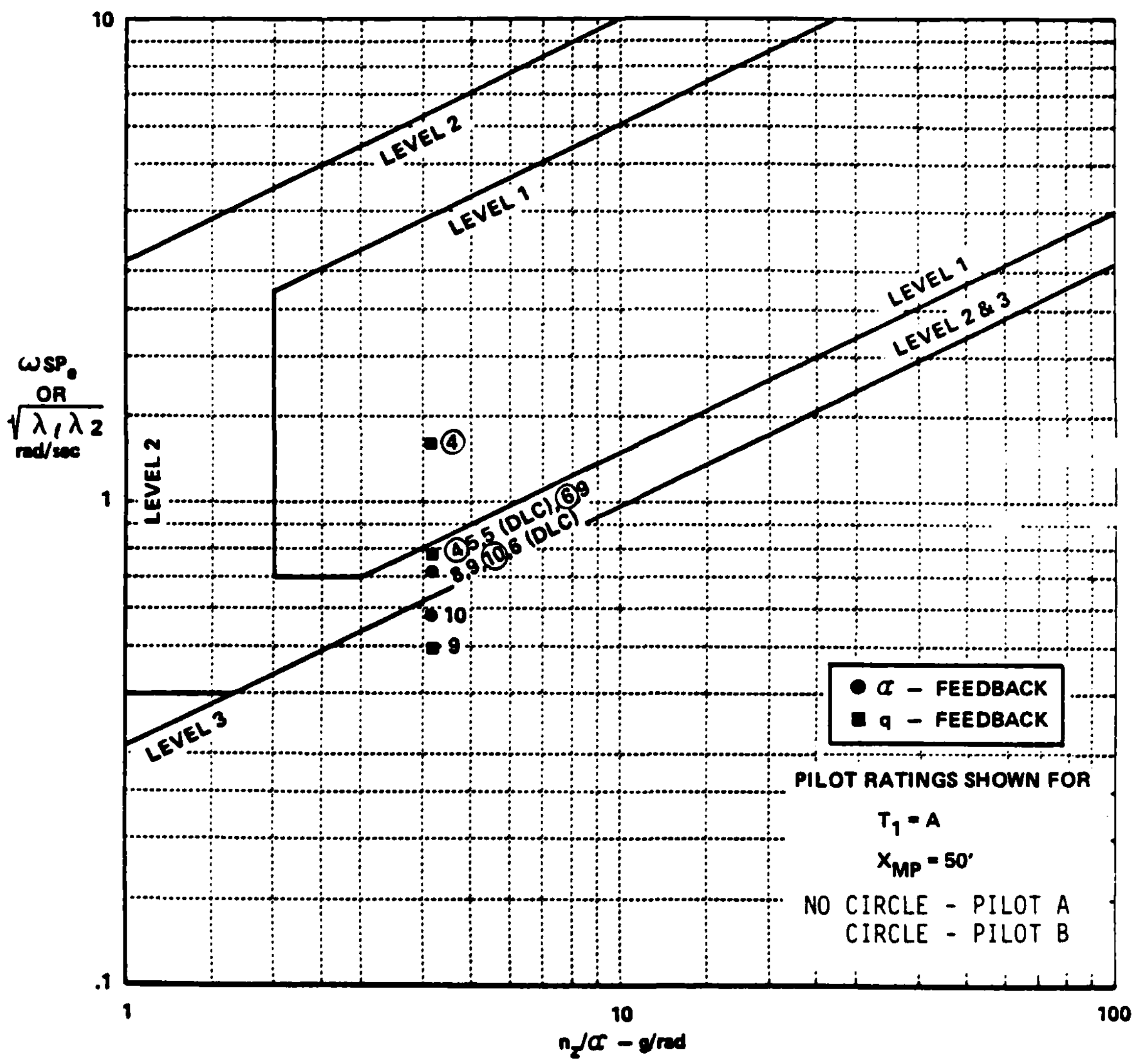


Figure V-A-3. SHORT AFT TAIL CONFIGURATIONS VS ω_{SP_e} REQUIREMENTS

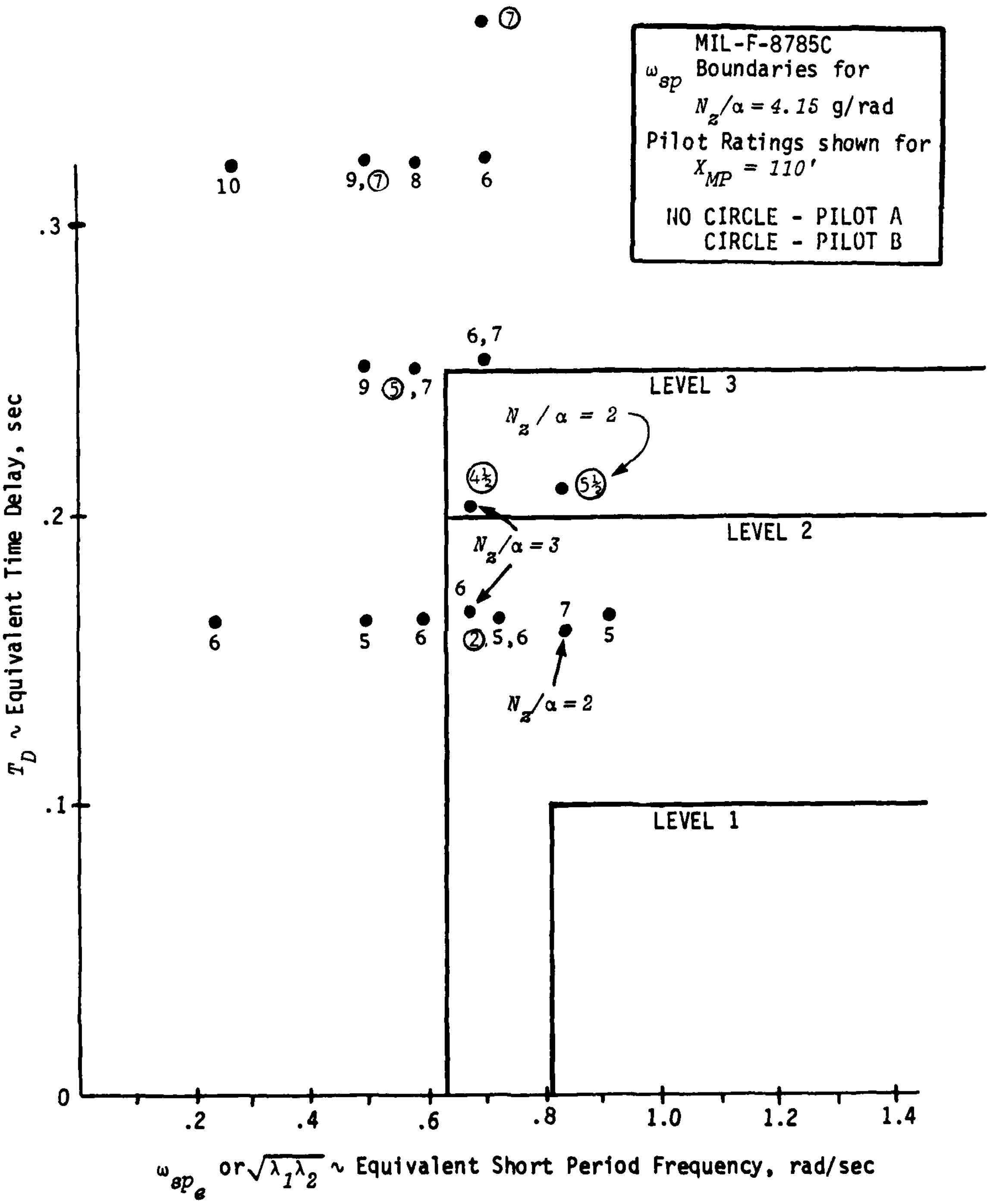


Figure V-A-4. LONG AFT TAIL α- FEEDBACK CONFIGURATIONS VS ALLOWABLE TIME DELAY

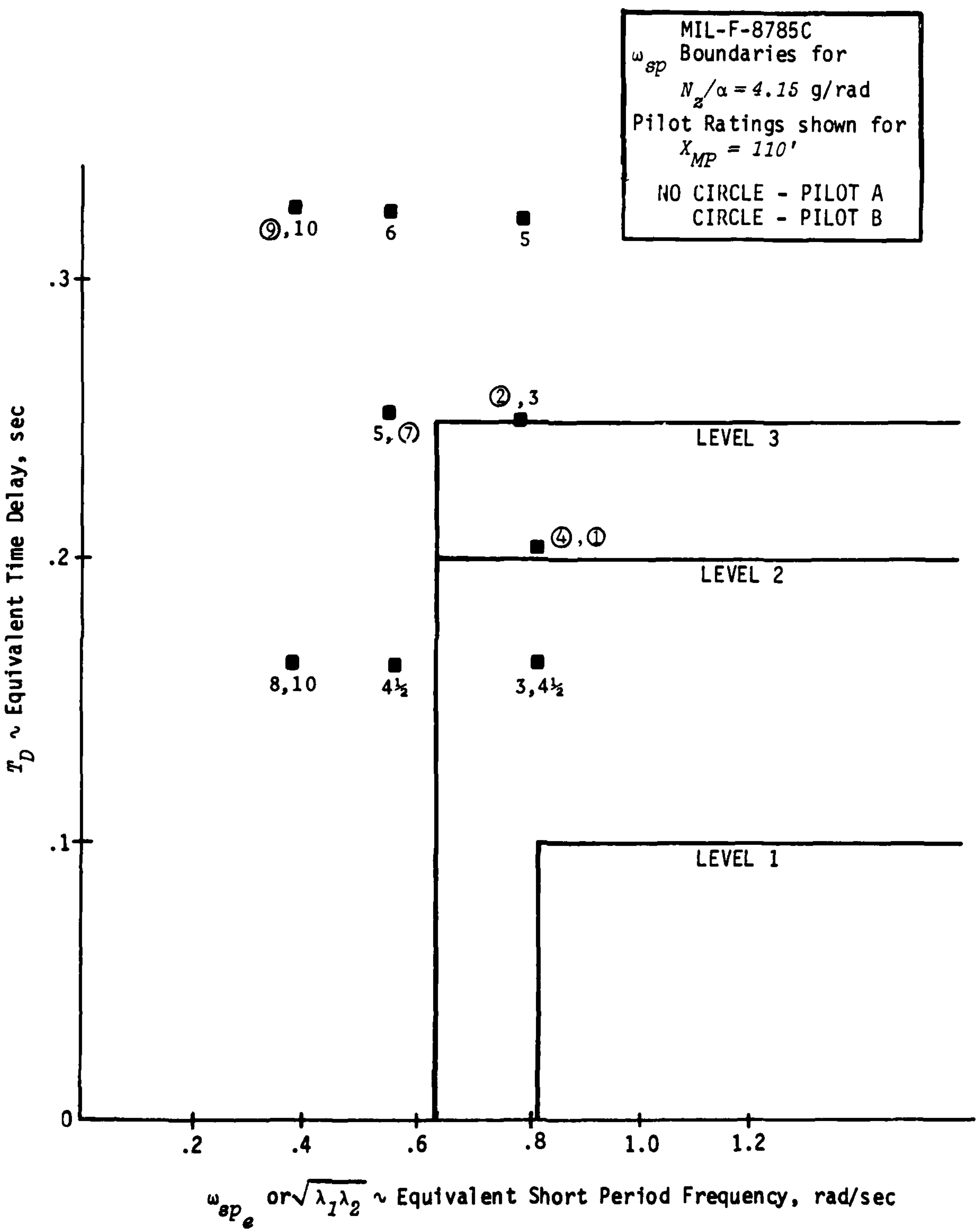


Figure V-A-5. LONG AFT TAIL q- FEEDBACK CONFIGURATIONS VS ALLOWABLE TIME DELAY

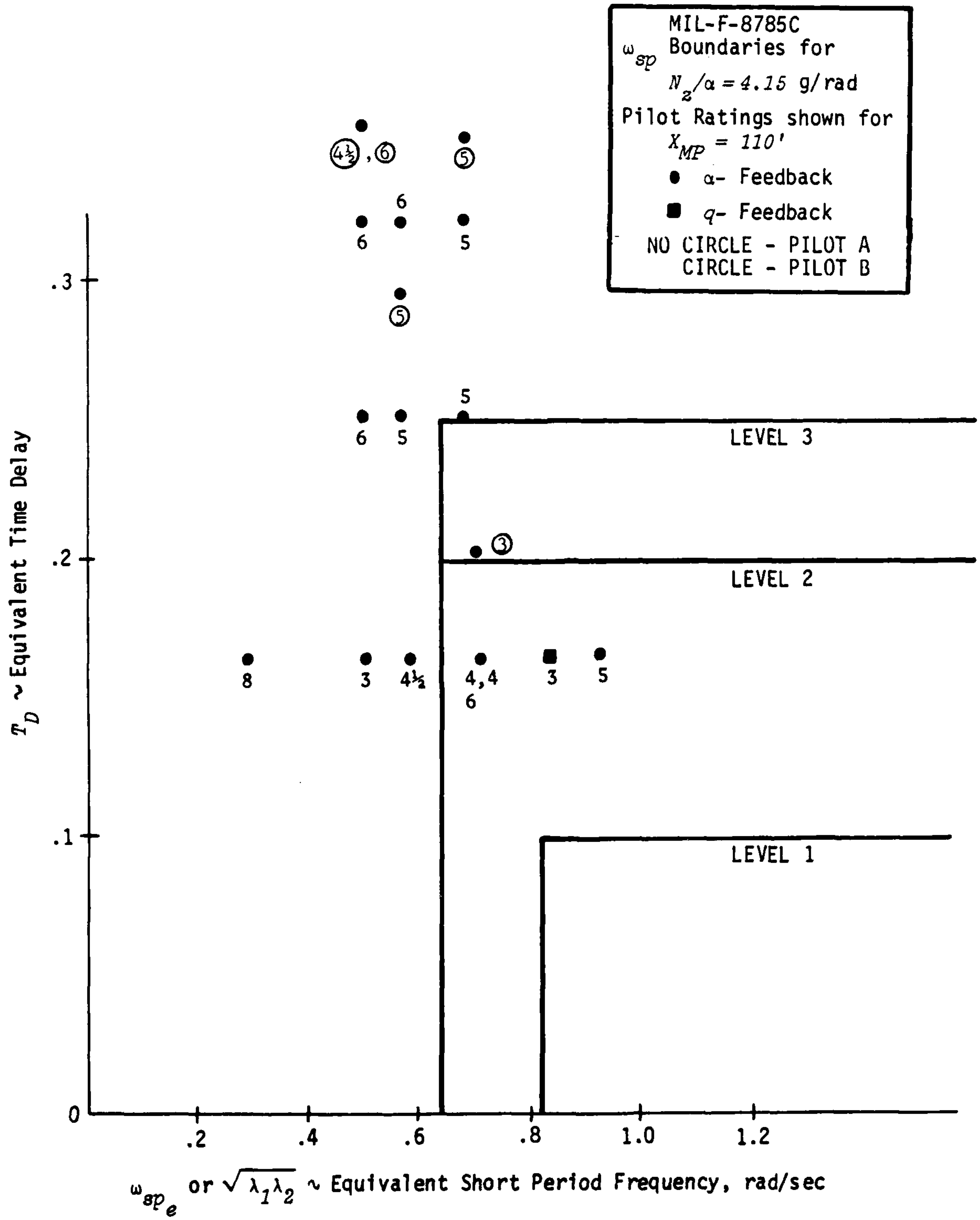


Figure V-A-6. CANARD CONFIGURATION VS ALLOWABLE TIME DELAY

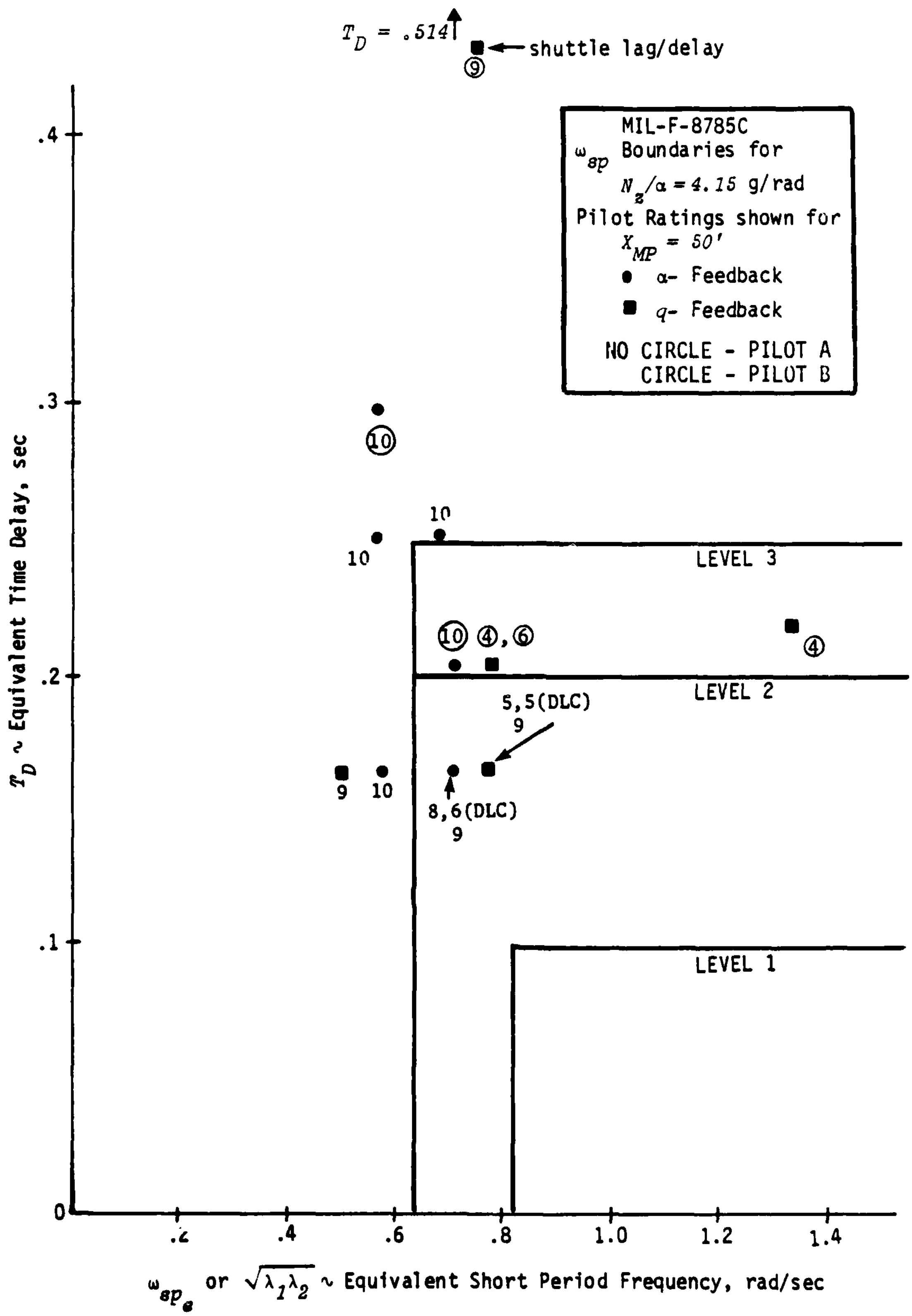


Figure V-A-7. SHORT AFT TAIL CONFIGURATIONS VS ALLOWABLE TIME DELAY

Appendix V-B

TIME HISTORY CRITERIA FOR PITCH RATE RESPONSE

The time history criteria for pitch rate response were developed in Reference 4 to correlate easily obtained parameters from a time history with flying qualities levels. It avoids identification of dominant roots or equivalent system models by working directly with the pitch rate transient response. To obtain the parameters for these criteria, the pitch rate response to a step input of pitch controller force is calculated from two-degree-of-freedom equations of motion (i.e., with speed constrained). The response should exhibit the characteristics defined below. Two straight lines are drawn on the pitch rate time history and the following measurements are defined. See Figure V-B-1.

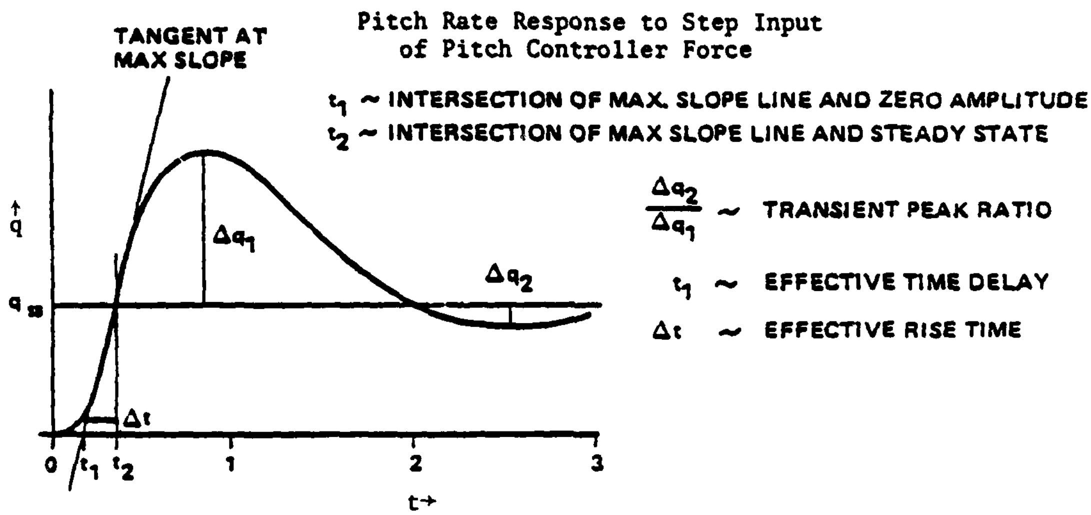


Figure V-B-1. TIME HISTORY CRITERIA PARAMETERS

a) A horizontal line defining the steady state pitch rate.

b) A sloping straight line tangent to the pitch rate time history at the point of maximum slope. This line is extended to intersect the steady state line and the time axis (maximum slope intercept).

c) Time t_1 is measured from the instant of the step input to the time corresponding to the intersection of the maximum slope line with the time axis.

d) Time t_2 is measured from the instant of the step input to the time corresponding to the intersection of the maximum slope line with the steady state line.

e) The amplitude quantities Δq_1 and Δq_2 are measured as follows: $\Delta q_1 \equiv$ maximum pitch rate minus the steady state; $\Delta q_2 \equiv$ the steady state minus the first minimum.

The above defined measurements shall meet the following design criteria.

Effective Time Delay

The time t_1 is considered an equivalent time delay and shall be within the limits specified below.

t_1 - effective time delay in command path

Level	Pitch
1	.12 sec
2	.17 sec
3	.21 sec

These time delay values are nominal values found tolerable for demanding control tasks (such as landing) in combination with good airplane dynamics. Significantly smaller command path time delays may be required to realize acceptable flying qualities in specific cases. Conversely, significantly larger values may be tolerable in less demanding tasks.

Transient Peak Ratio

The transient peak ratio $\Delta q_2/\Delta q_1$ shall be equal to or less than the following:

Level	$\Delta q_2/\Delta q_1$
1	.30
2	.60
3	.85

Rise Time Parameter

The parameter $\Delta t = t_2 - t_1$ shall have a value between the following limits:

	Nonterminal Flight Phases		Terminal Flight Phases
Level	Min Δt Max	Level	Min Δt Max
1	$\frac{(9)}{V_T} \leq \Delta t \leq \frac{(500)}{V_T}$	1	$\frac{(9)}{V_T} \leq \Delta t \leq \frac{(200)}{V_T}$
2	$\frac{(3.2)}{V_T} \leq \Delta t \leq \frac{(1600)}{V_T}$	2	$\frac{(3.2)}{} \leq \Delta t \leq \frac{(645)}{V_T}$

where: V_T - ft/sec, true airspeed.

Constant-speed pitch rate responses to step force (F_{ES}) input were computed for all of the configurations with the 25 rad/sec feel system. These are presented at the end of this Appendix. The effective time delay (t_1), including the TIFS pitch model-following delay of .06 seconds, and rise time parameter (Δt) were measured from these responses and are tabulated on *Table V-B-1*. Transient peak ratio is not presented, as the values for this parameter were Level 1 for all configurations. The results from this analysis are also presented in Figures V-B-2 through V-B-4 where the configurations with pilot ratings are spotted on the effective time delay and rise time plane. Flying qualities levels are indicated on these figures. For the rise time parameter, V_T = 253.2 ft/sec and the terminal flight phase limits were used.

TABLE V-B-1. TIME HISTORY CRITERIA

Pitch rate response to step force input.

t_1 ~ Effective time delay, sec — maximum slope intercept

Δt ~ Effective rise time, sec — time between maximum slope intercept of time axis and steady state value

25 rad/sec feel system used. t_1 with 15 r/s feel system are .04 sec longer

CONFIGURATION		LEVEL OF DELAY (T_1)					
		A		B		C	
		t_1	Δt	t_1	Δt	t_1	Δt
Long Aft Tail	Unaug.	.13	---			.30	---
	Low α gain	.15	2.26	.23	2.52	.30	2.55
	Med α	.14	1.51	.23	1.66	.31	1.66
	High α	.15	.96	.22	1.15	.30	1.11
	Ex-High α	.14	.62				
	High α, $N_z/\alpha = 3$	.14	.76				
	High α, $N_z/\alpha = 2$	.14	.49				
	Low q gain	.16	3.21			.37	3.20
	Med q	.14	1.65	.23	1.76	.32	1.72
	High q	.14	.84	.22	.95	.29	.97
Canard	Unaug.	.14	---				
	Low α gain	.14	2.19	.23	2.43	.30	2.46
	Med α	.14	1.56	.22	1.74	.30	1.74
	High α	.14	1.02	.22	1.12	.30	1.13
	Ex-High α	.13	.60				
	High q	.14	.80				

TABLE V-B-1. TIME HISTORY CRITERIA (CONT'D)

Pitch rate response to step force input.

t_1 ~ Effective time delay, sec — maximum slope intercept

Δt ~ Effective rise time, sec — time between maximum slope intercept of time axis and steady state value

25 rad/sec feel system used. t_1 with 15 rad/sec feel system are .04 sec longer.

CONFIGURATION		LEVEL OF DELAY (T_1)					
		A		B		C	
		t_1	Δt	t_1	Δt	t_1	Δt
Short Aft Tail	Med α gain	.14	1.59	.23	1.74		
	High α	.14	1.03	.22	1.16		
	Med q gain	.14	2.06				
	High q	.13	.94			(.39	1.06)*
	Ex-High q	.14	.44				

*T_1 = .35 (shuttle lag/delay)

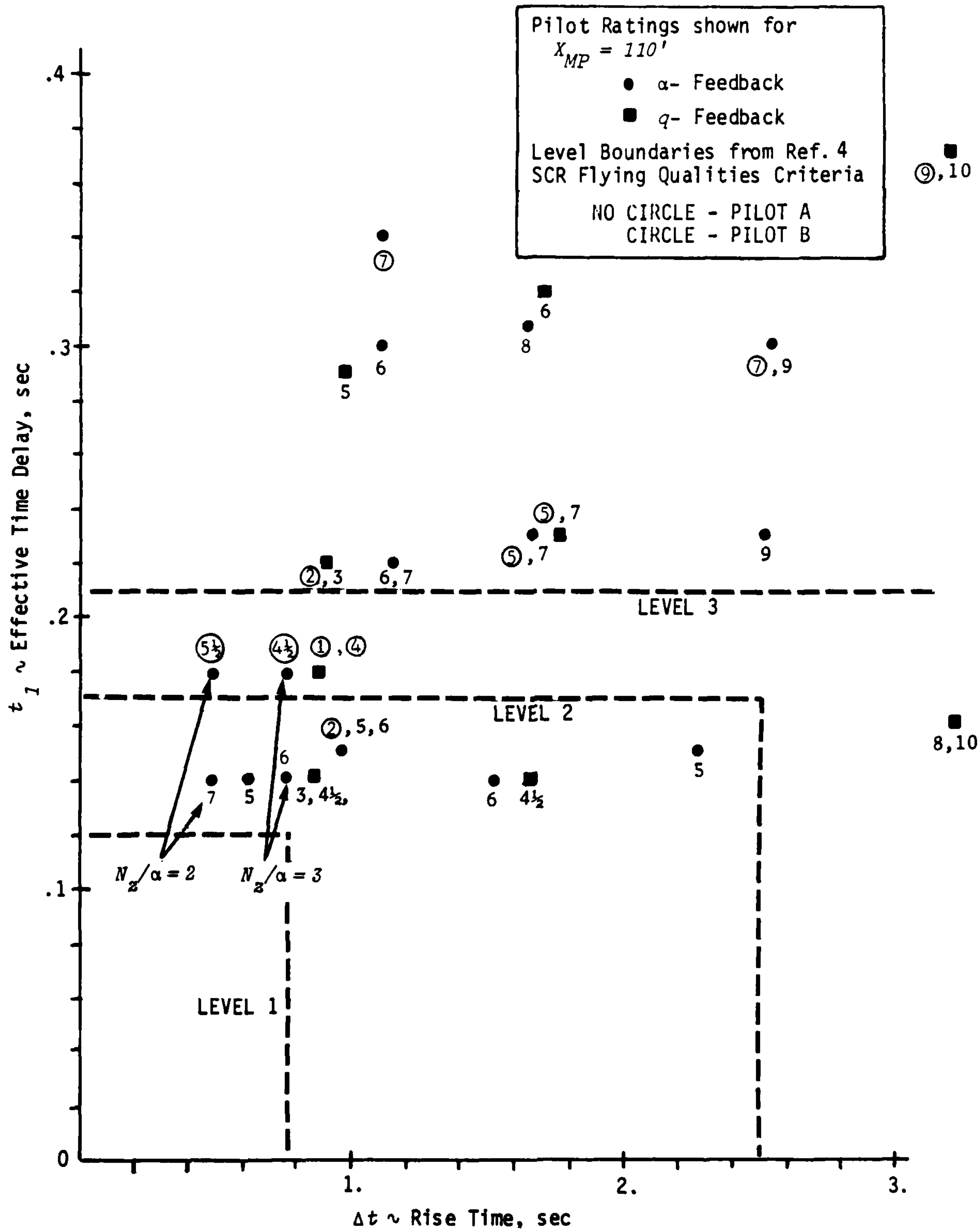


Figure V-B-2. LONG AFT TAIL CONFIGURATIONS VS TIME HISTORY CRITERIA

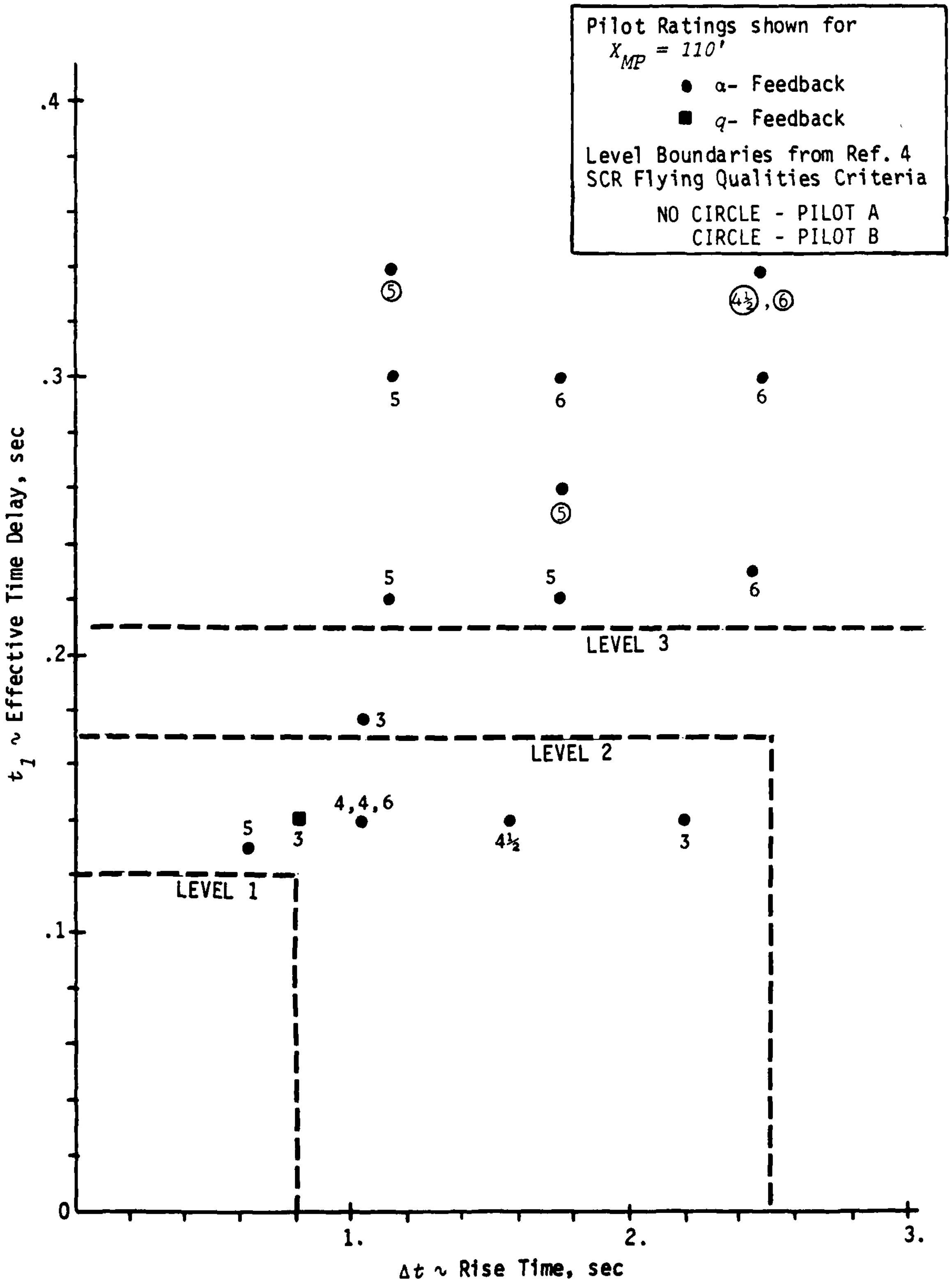


Figure V-B-3. CANARD CONFIGURATIONS VS TIME HISTORY CRITERIA

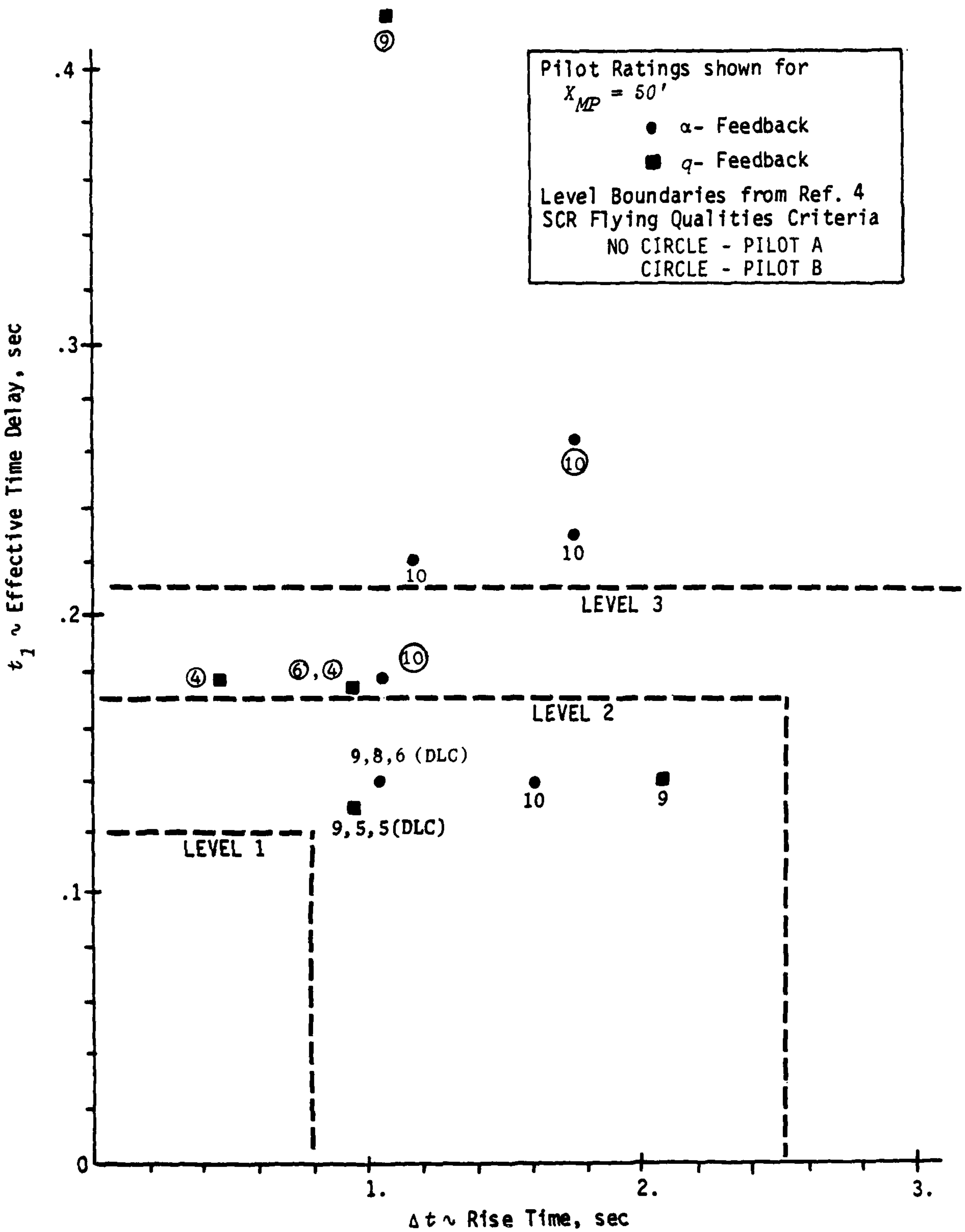
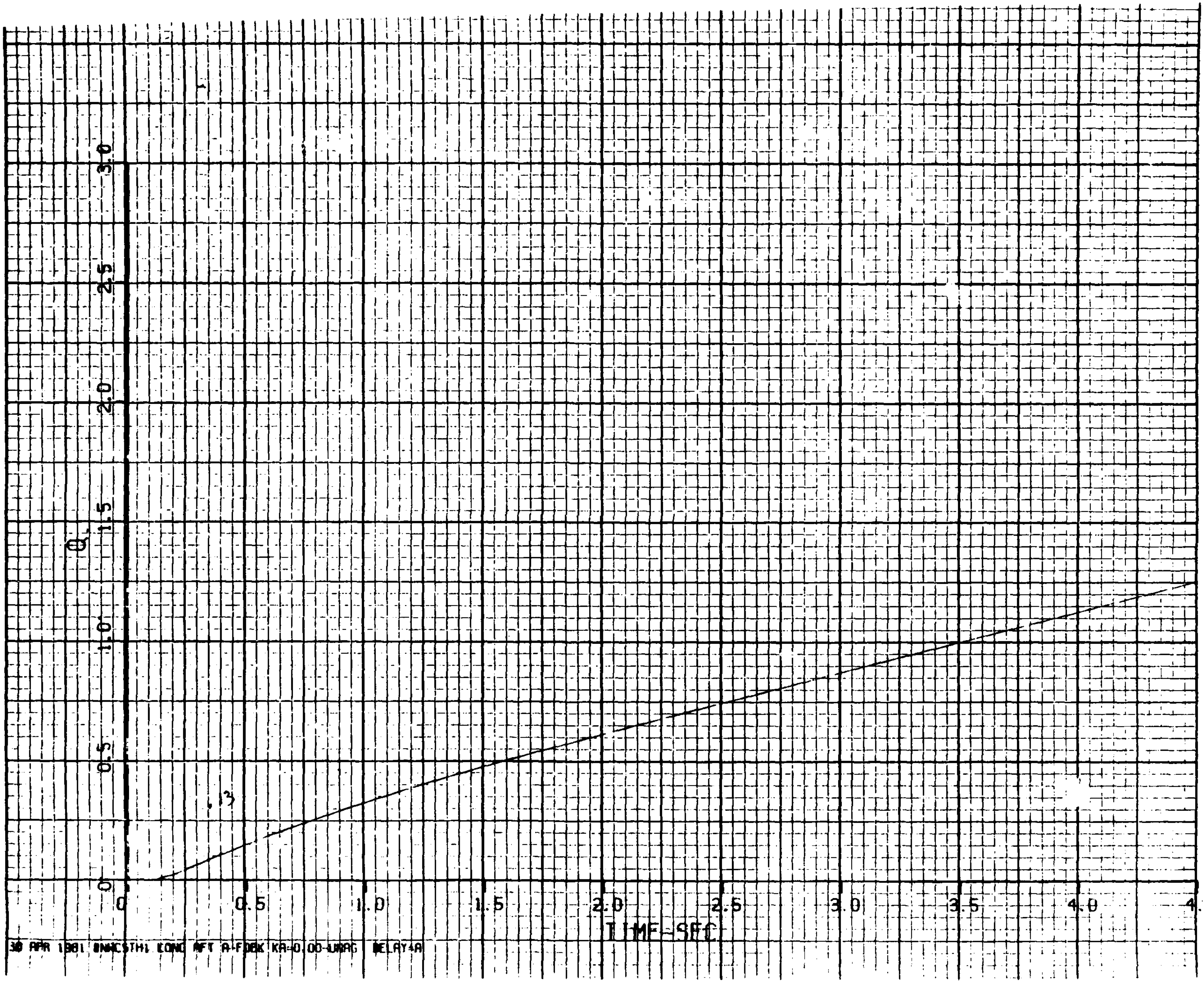


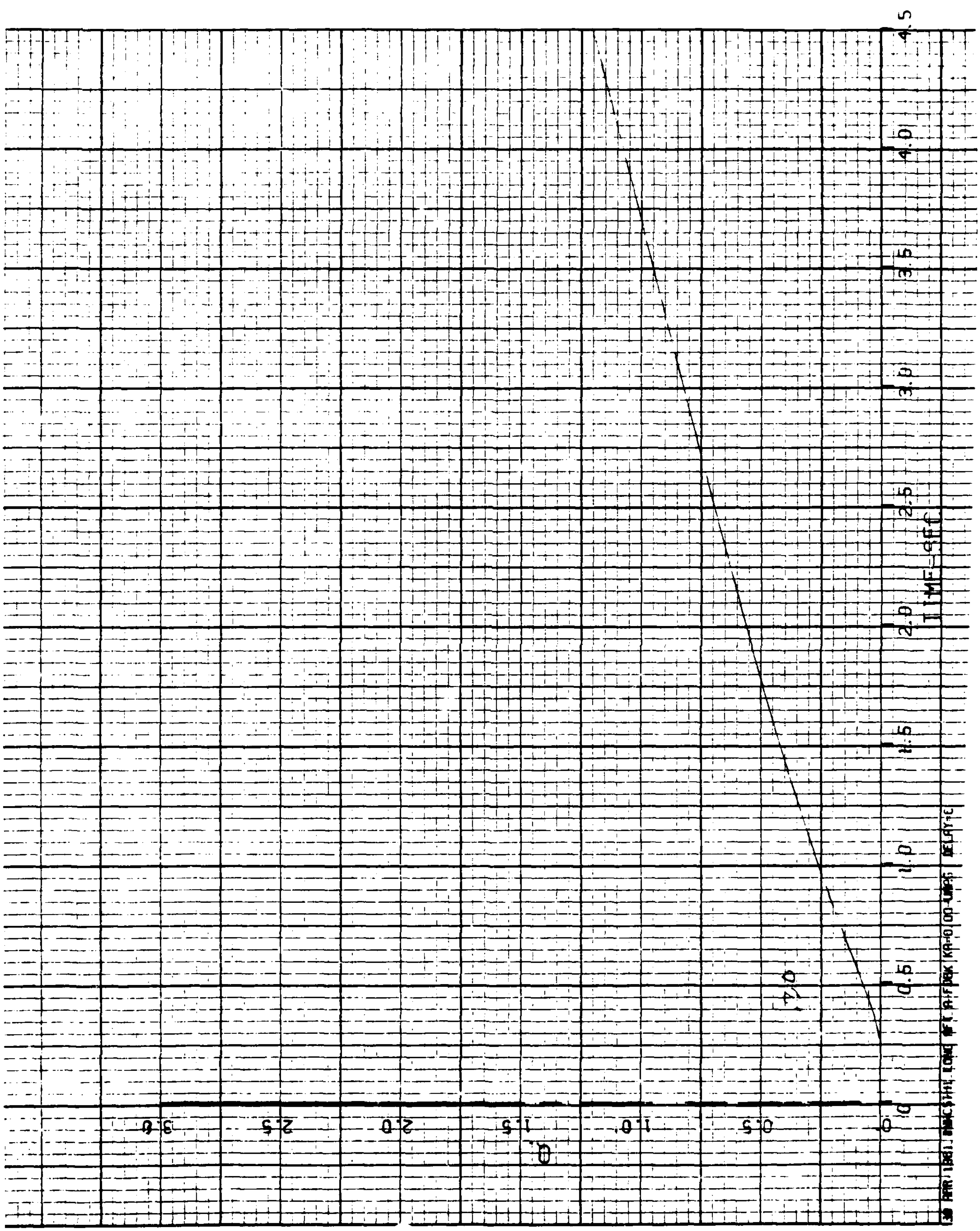
Figure V-B-4. SHORT AFT TAIL CONFIGURATIONS VS TIME HISTORY CRITERIA

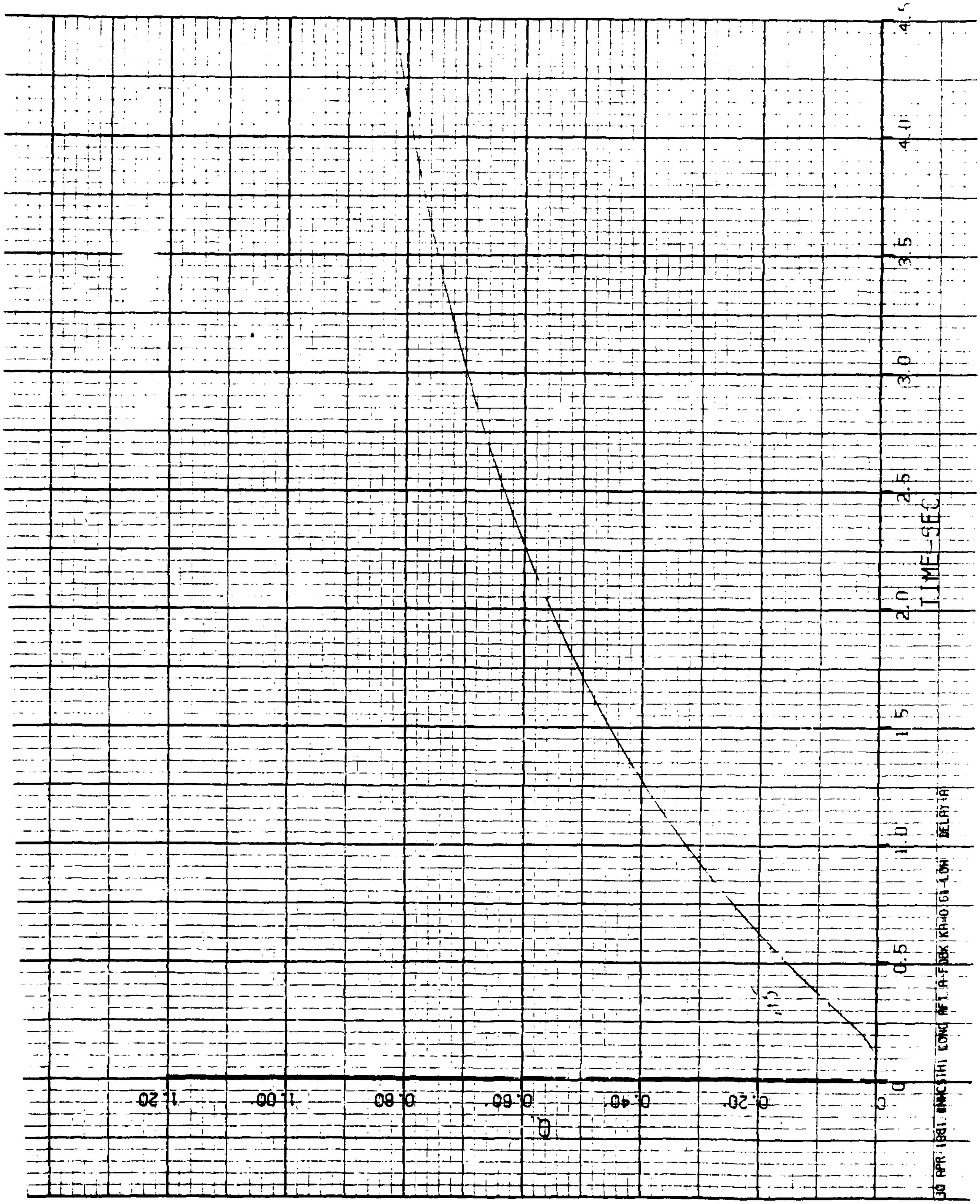
PITCH RATE RESPONSE — TIME HISTORY CRITERIA PLOTS

The following figures present the constant-speed time histories of pitch rate response to a step force input for each configuration evaluated. The captions beneath each time history define the configuration. The time histories were normalized so that the steady state for each configuration (except the unaugmented ones) was 1. The TIFS pitch model-following delay of .06 seconds is included. The 25 r/s feel system was used. The 15 r/s feel system would increase t_1 by approximately .04 sec. From these time histories effective time delay (t_1) and rise time (Δt) parameters were measured.

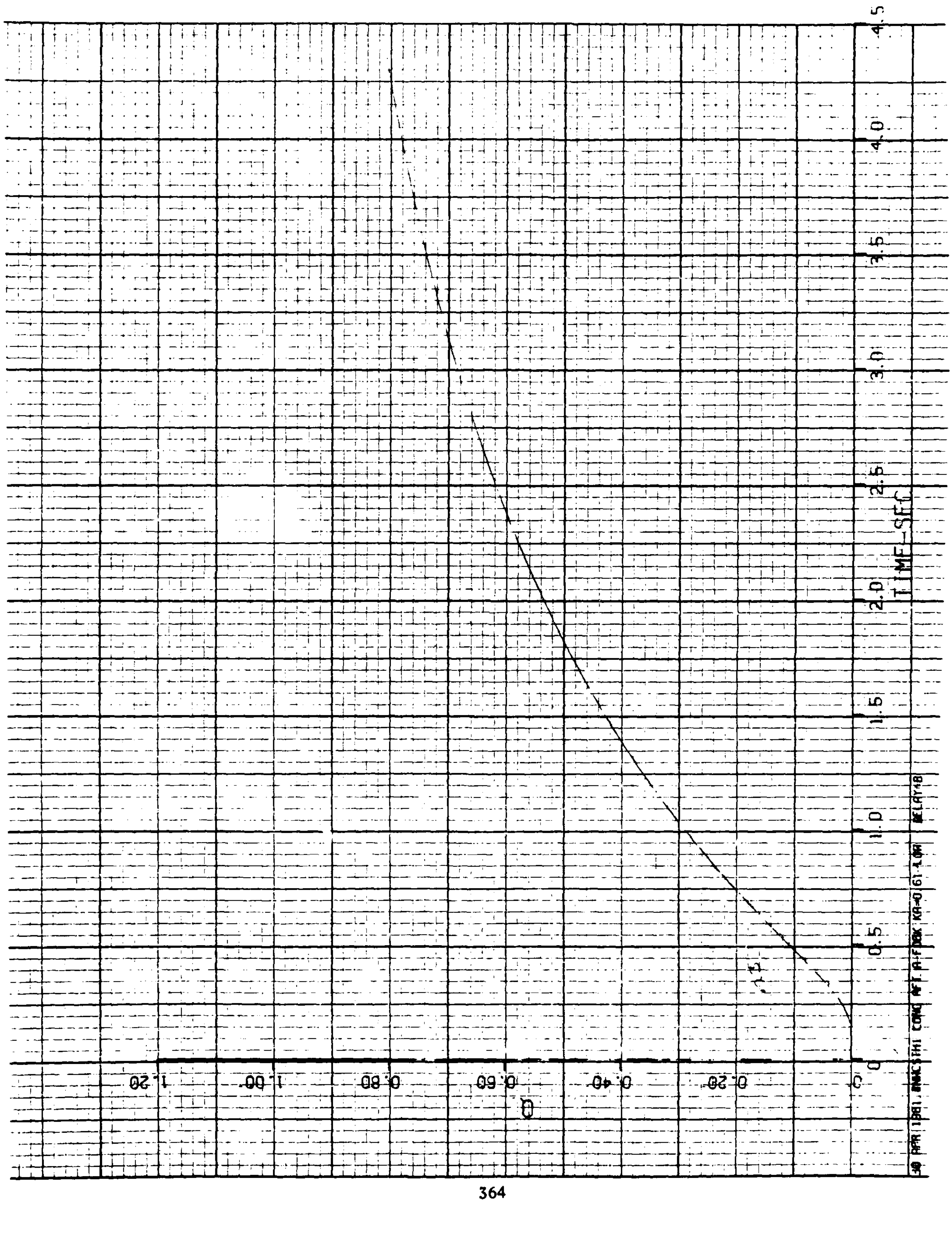


Q
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
TIME-SEC
.13
30 APR 1981

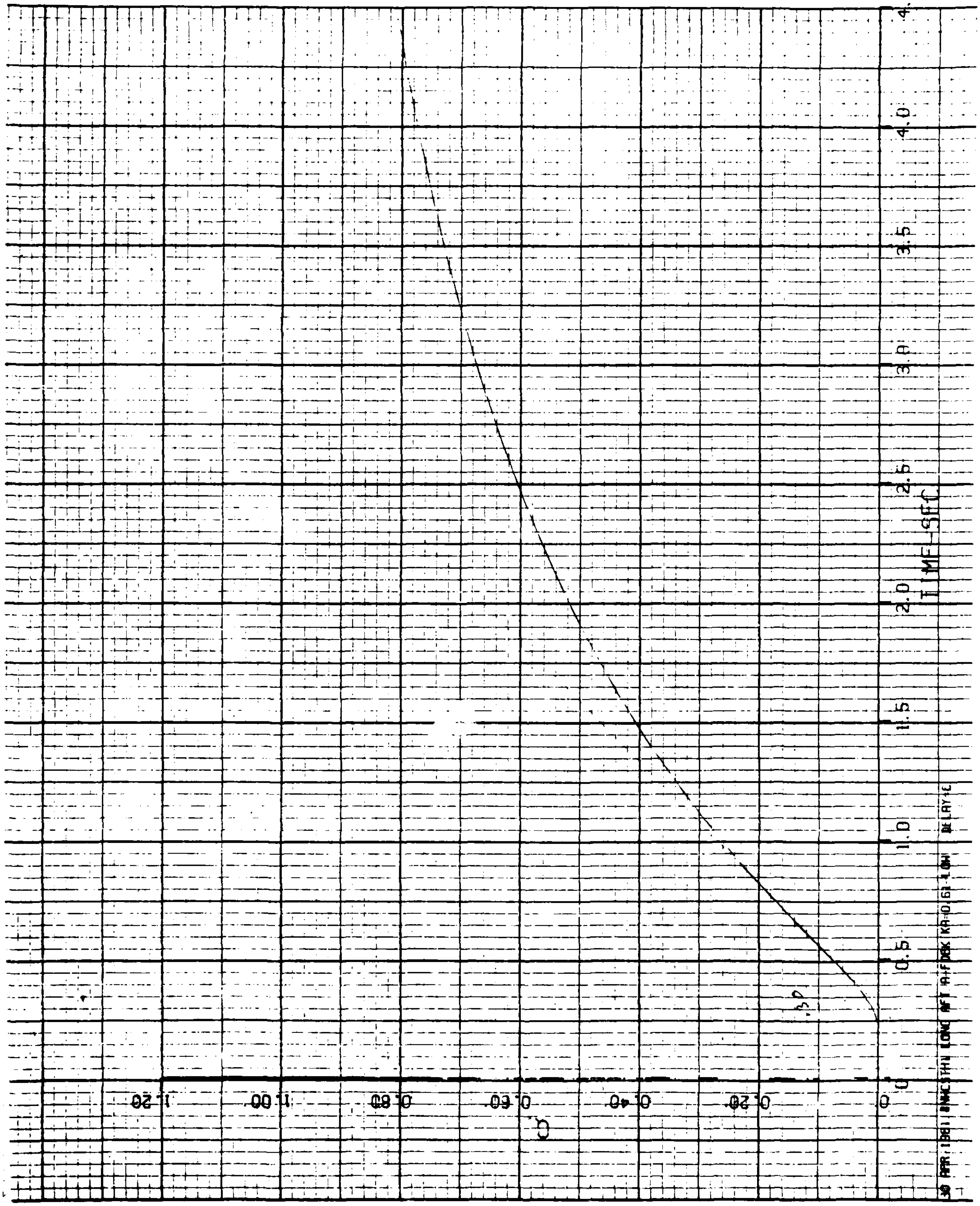

TIME - SEC
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
θ



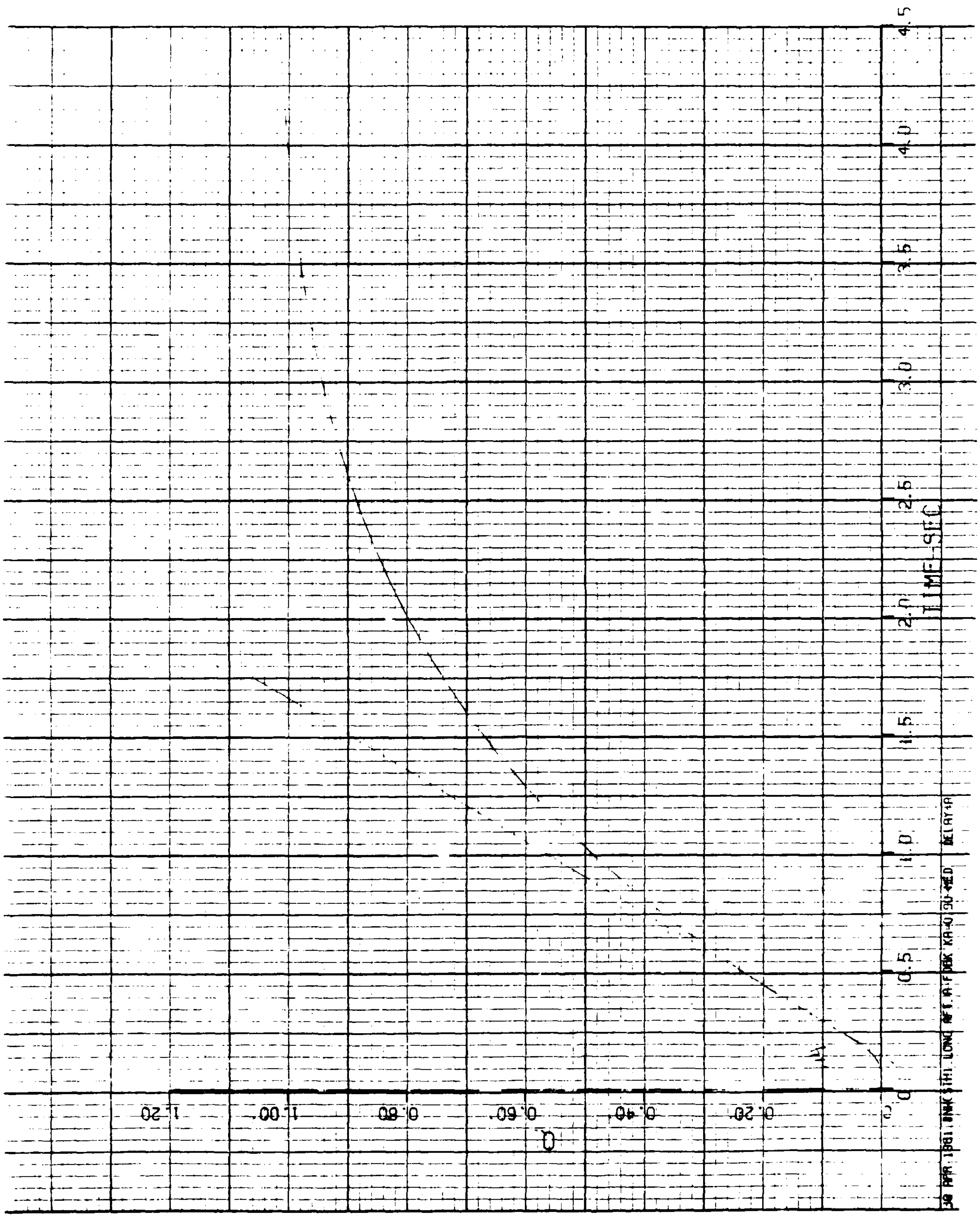
30 APR 1981 NNACSTH1 LONG AFT A-FDBK KA=0 61 LOW DELAY(A)
TIME-SEC
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
0
0.20
0.40
0.60
0.80
1.00
1.20
θ

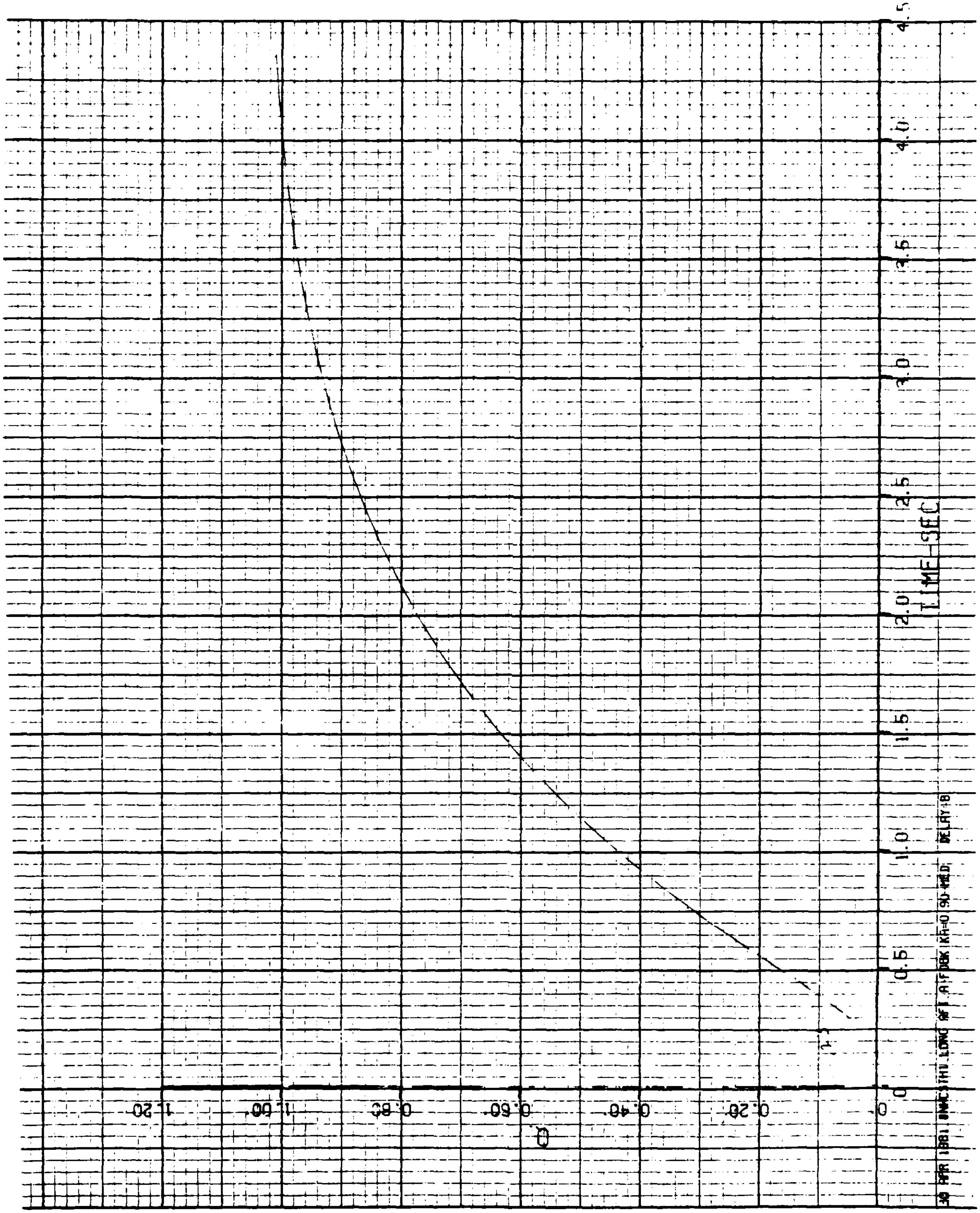


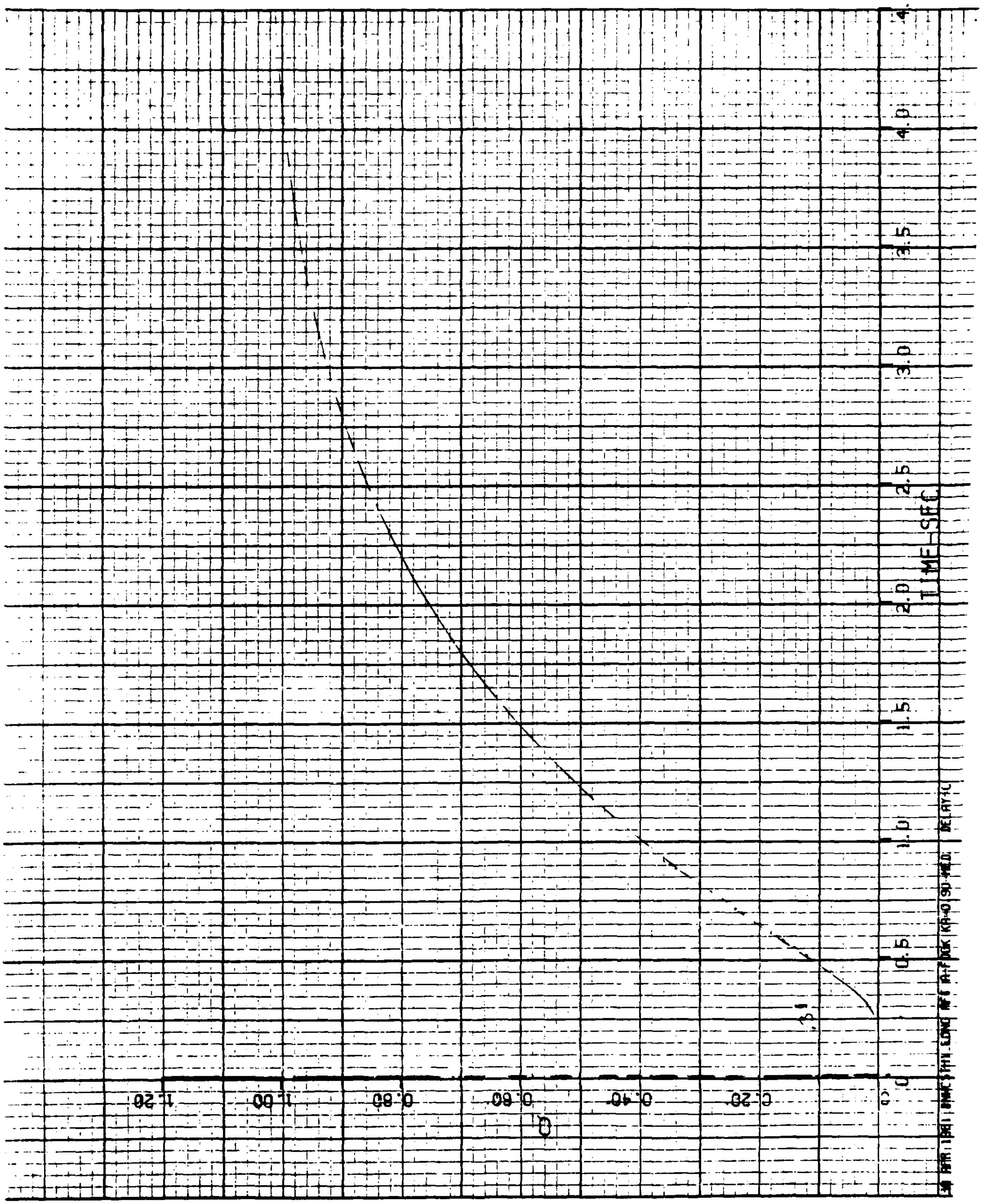
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
TIME-SEC
0
0.20
0.40
0.60
0.80
1.00
1.20
Q



0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
TIME-SEC
0
0.20
0.40
0.60
0.80
1.00
1.20
C


TIME-SEC
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Q
0.20
0.40
0.60
0.80
1.00
1.20


TIME-SEC
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Q
0
0.20
0.40
0.60
0.80
1.00
1.20
DELAY 8


TIME-SEC
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0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Q
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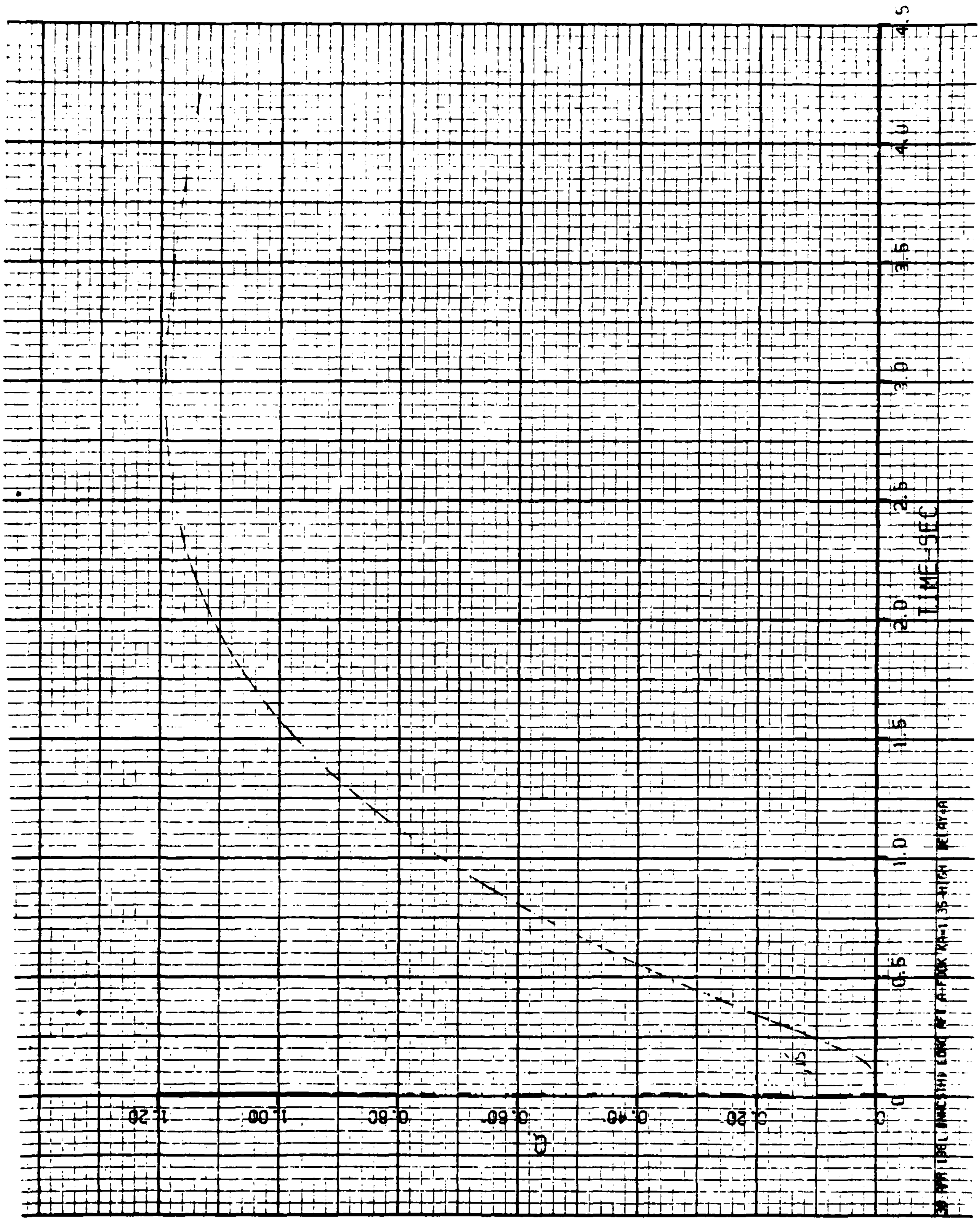
0.40
0.60
0.80
1.00
1.20
3.1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1.5
2.0
2.5
3.0
3.5
4.0
4.5
C
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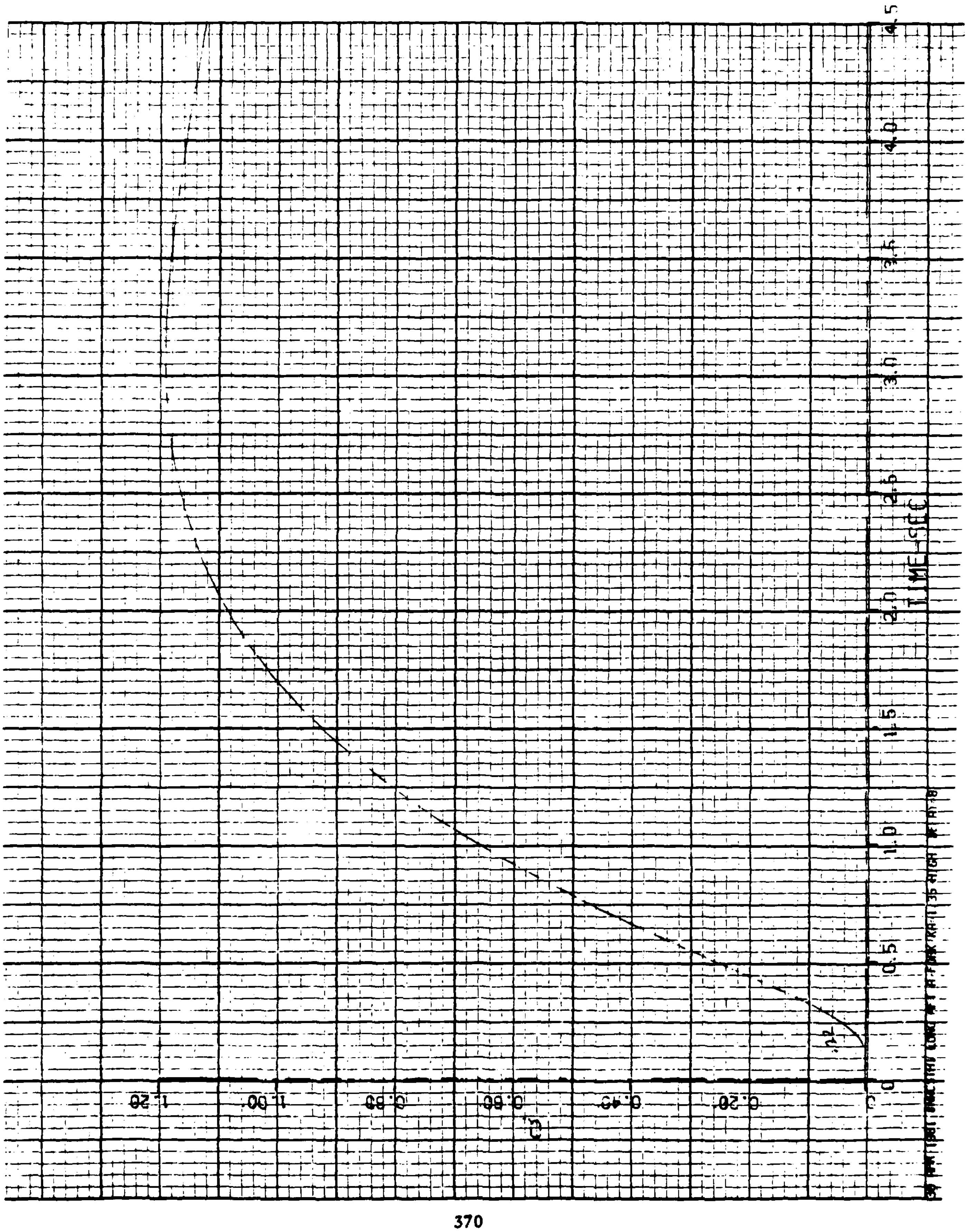
0.40
0.60
0.80
1.00
1.20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2.0
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4.5
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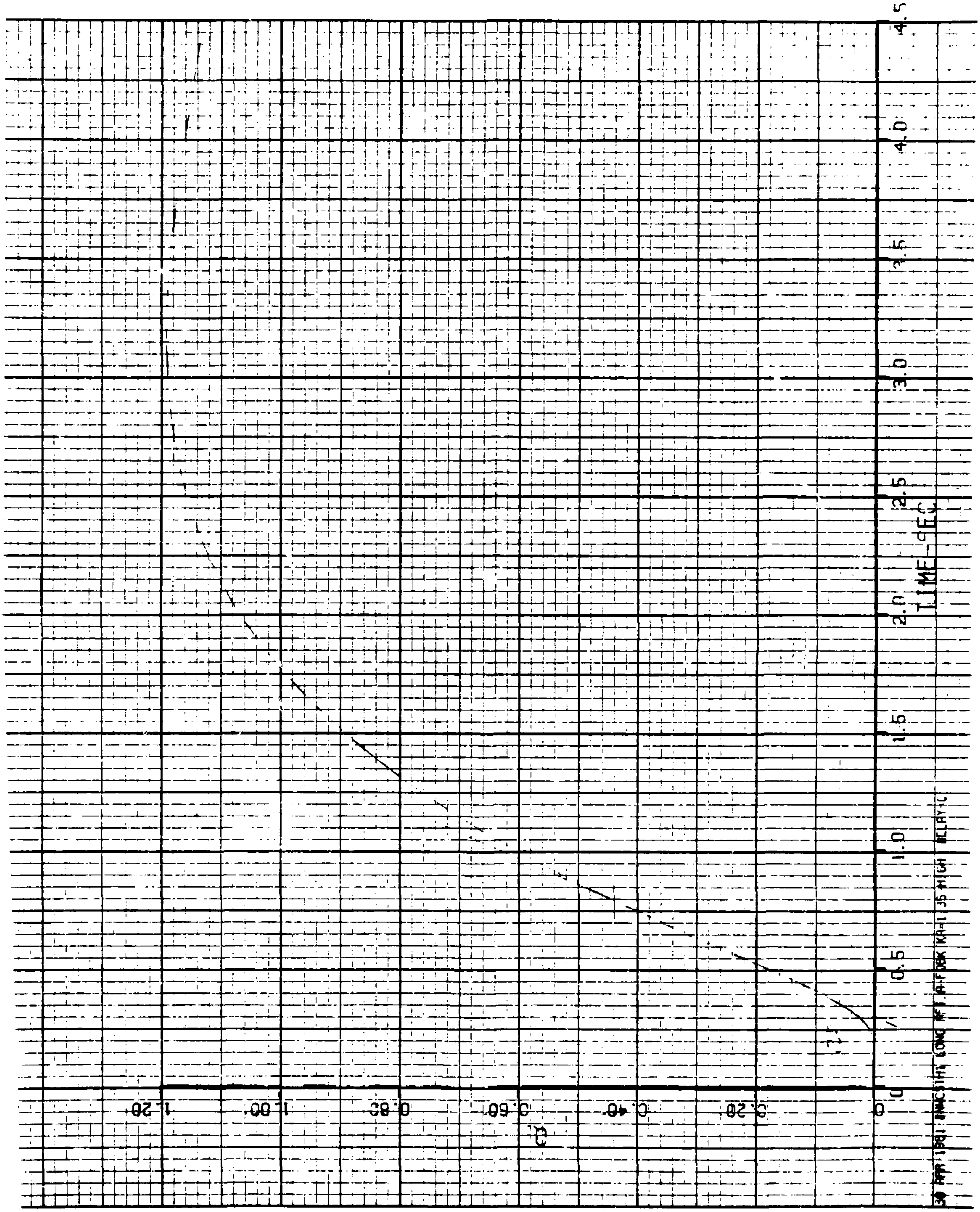
0.40
0.60
0.80
1.00
1.20


TIME-SEC
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1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
Q
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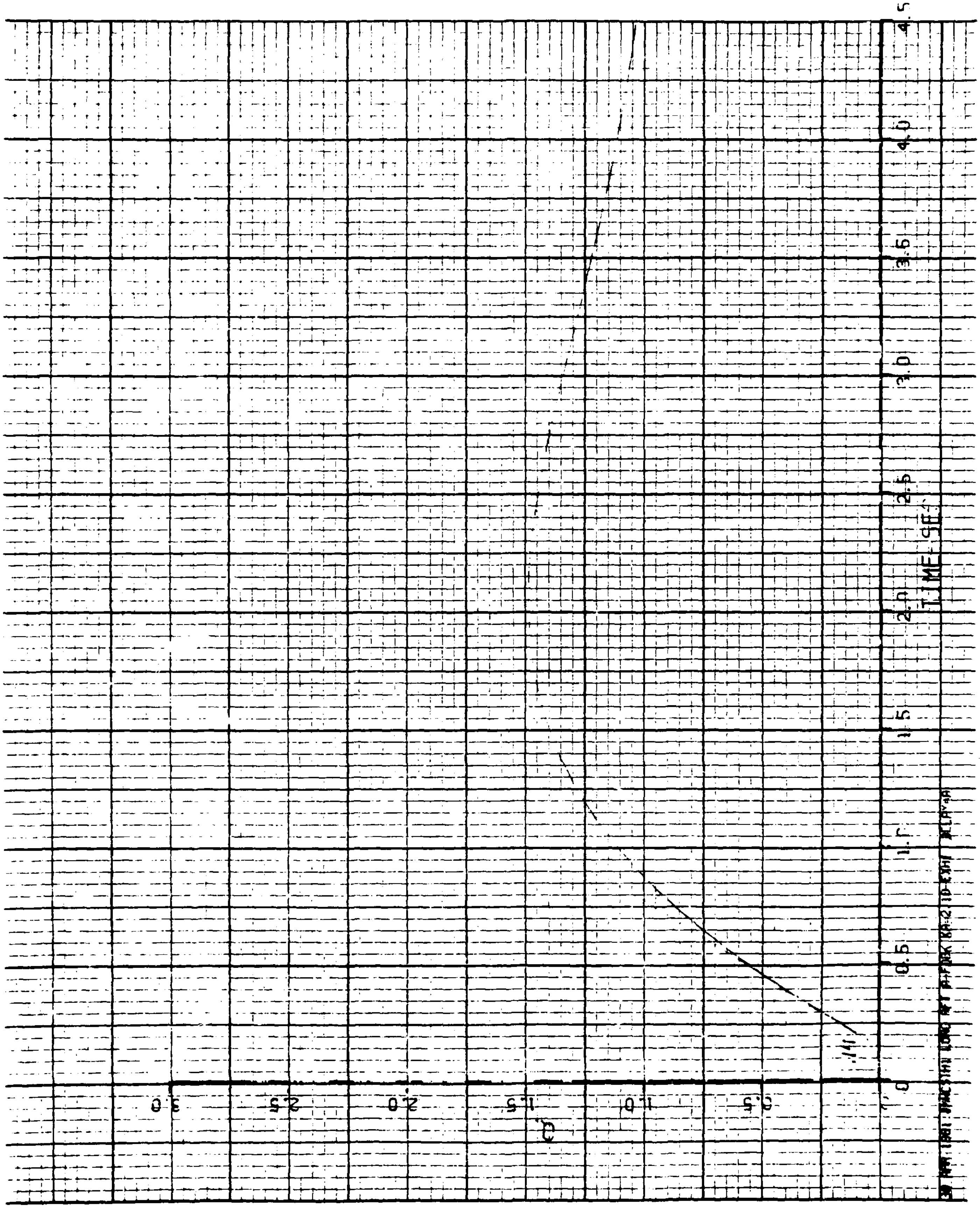
0.40
0.60
0.80
1.00
1.20


TIME- SEC
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2.5
3.0
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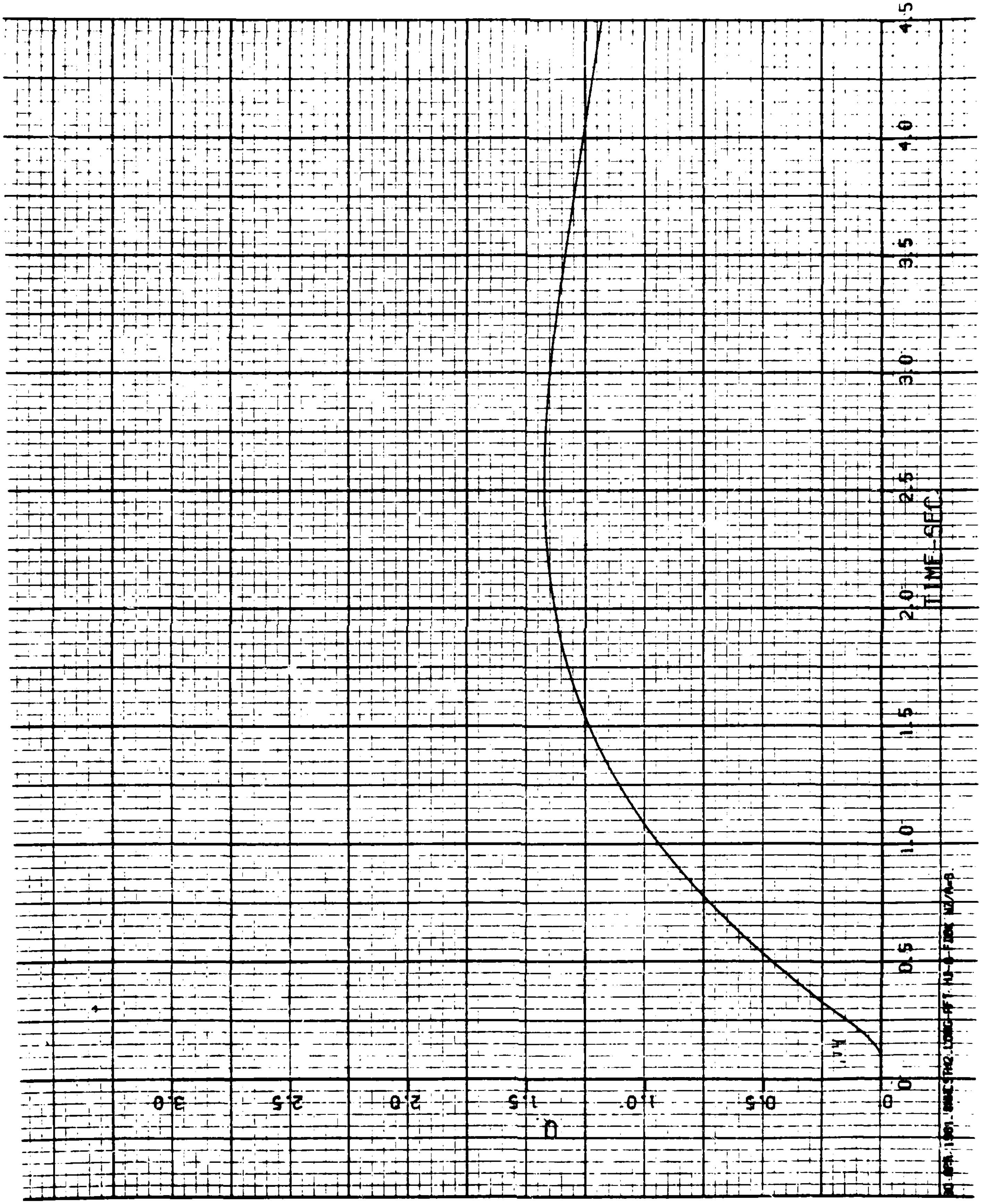
4.0
4.5



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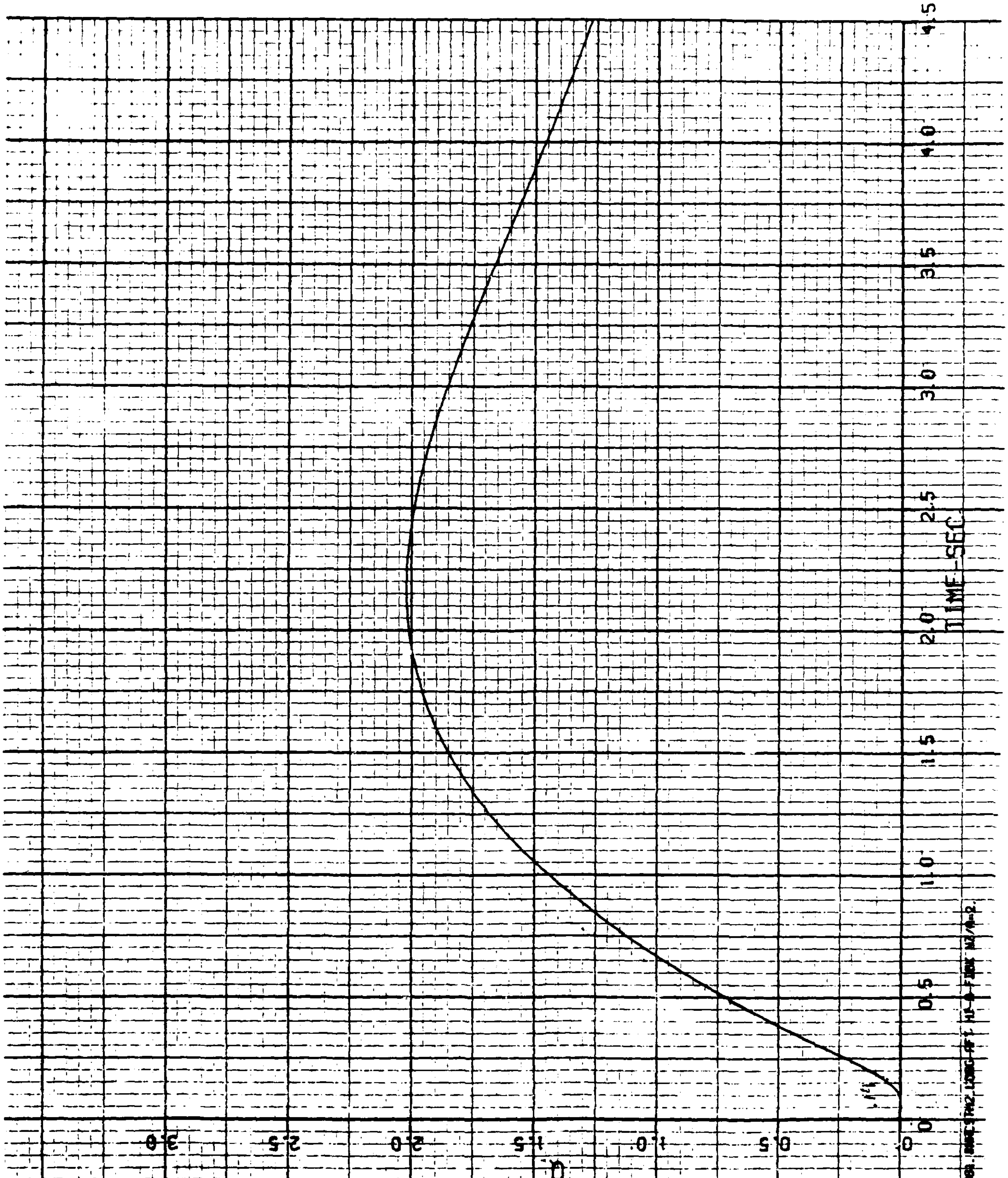
4.0
4.5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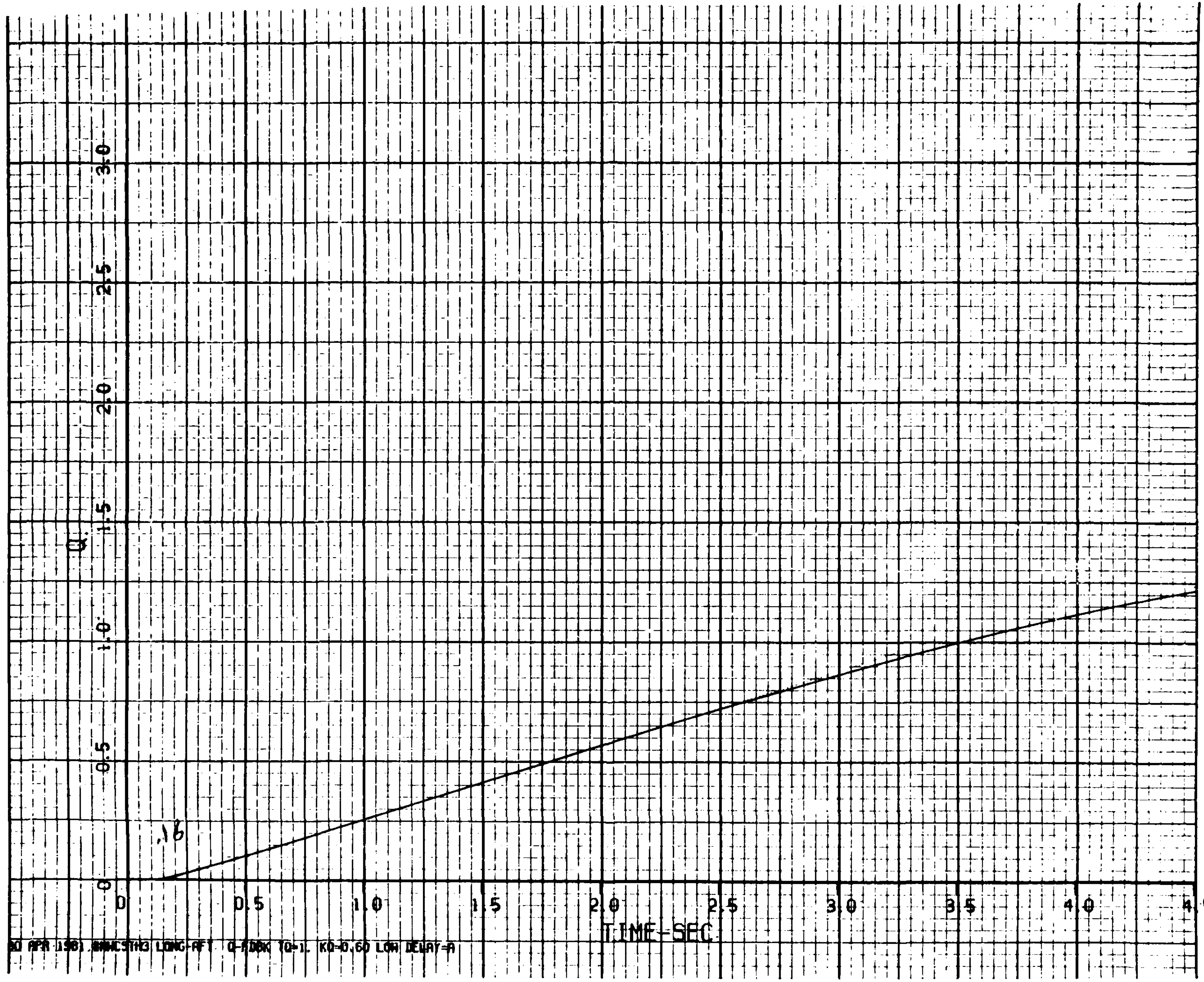
2.5
3.0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2.0
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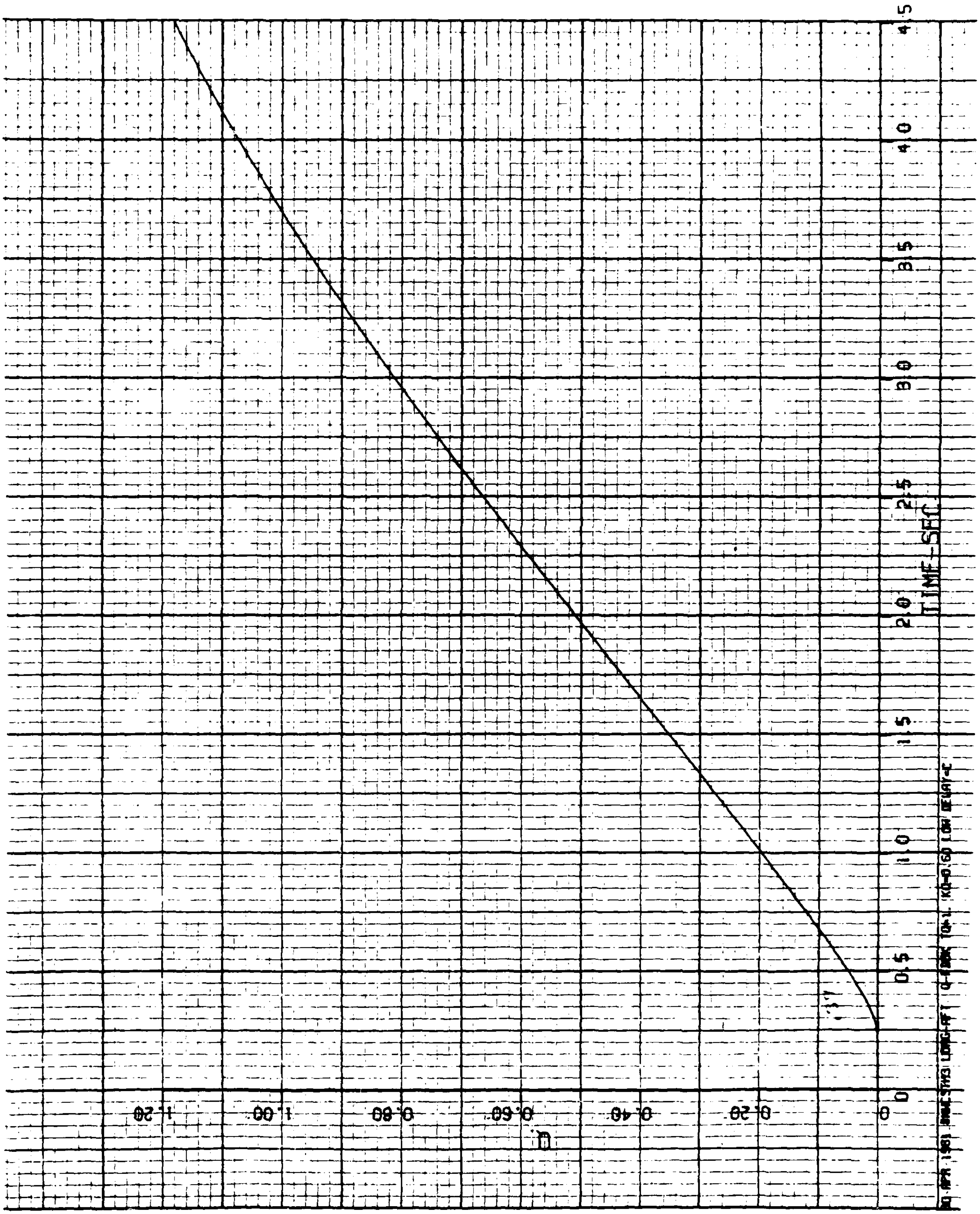
0.5
0
Q
.16
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
TIME-SEC
APR 1981
LONG-AFT
KQ=0.60 LOW DELAY=A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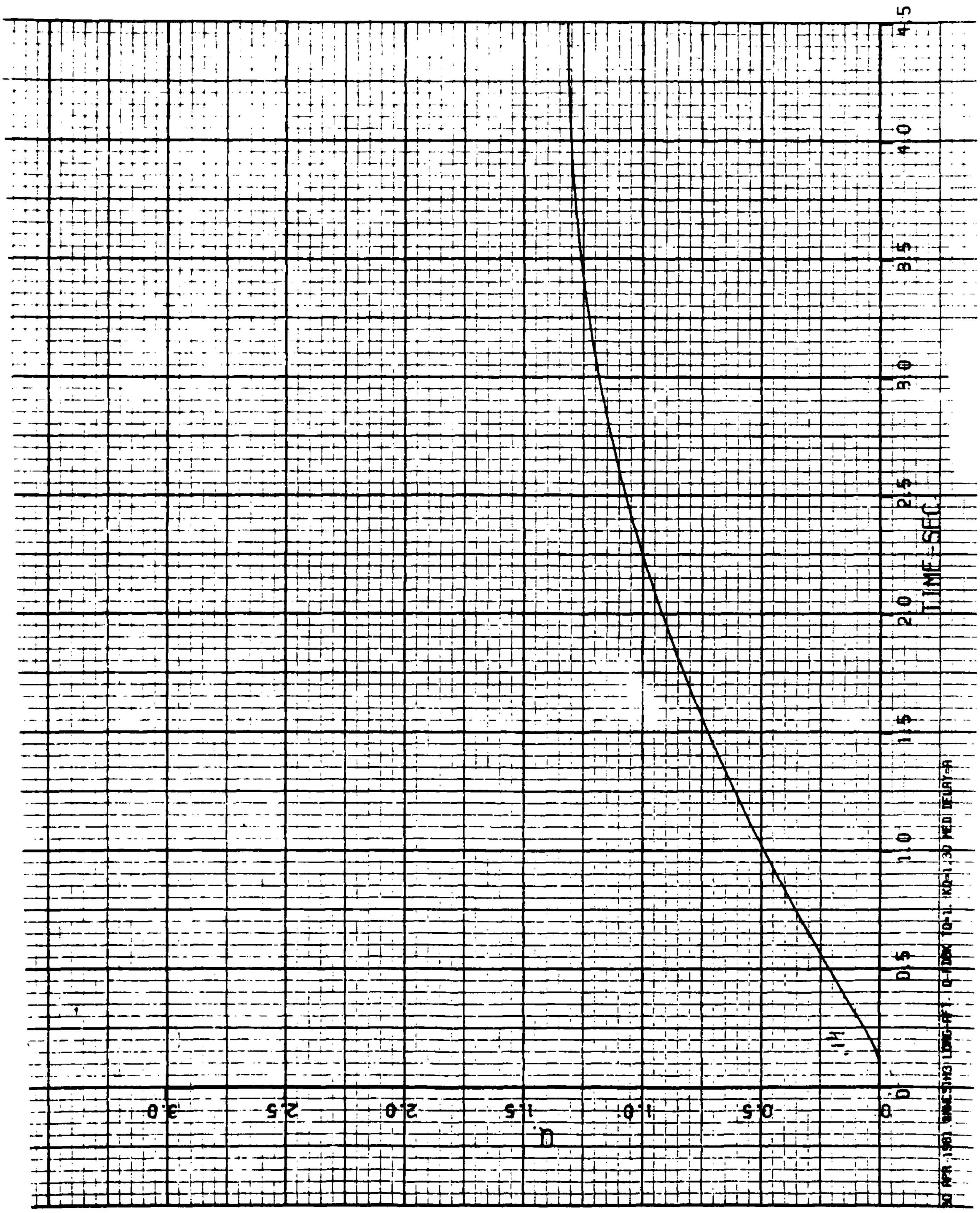
1.20



TIME-SEC
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1.0
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2.0
2.5
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Q
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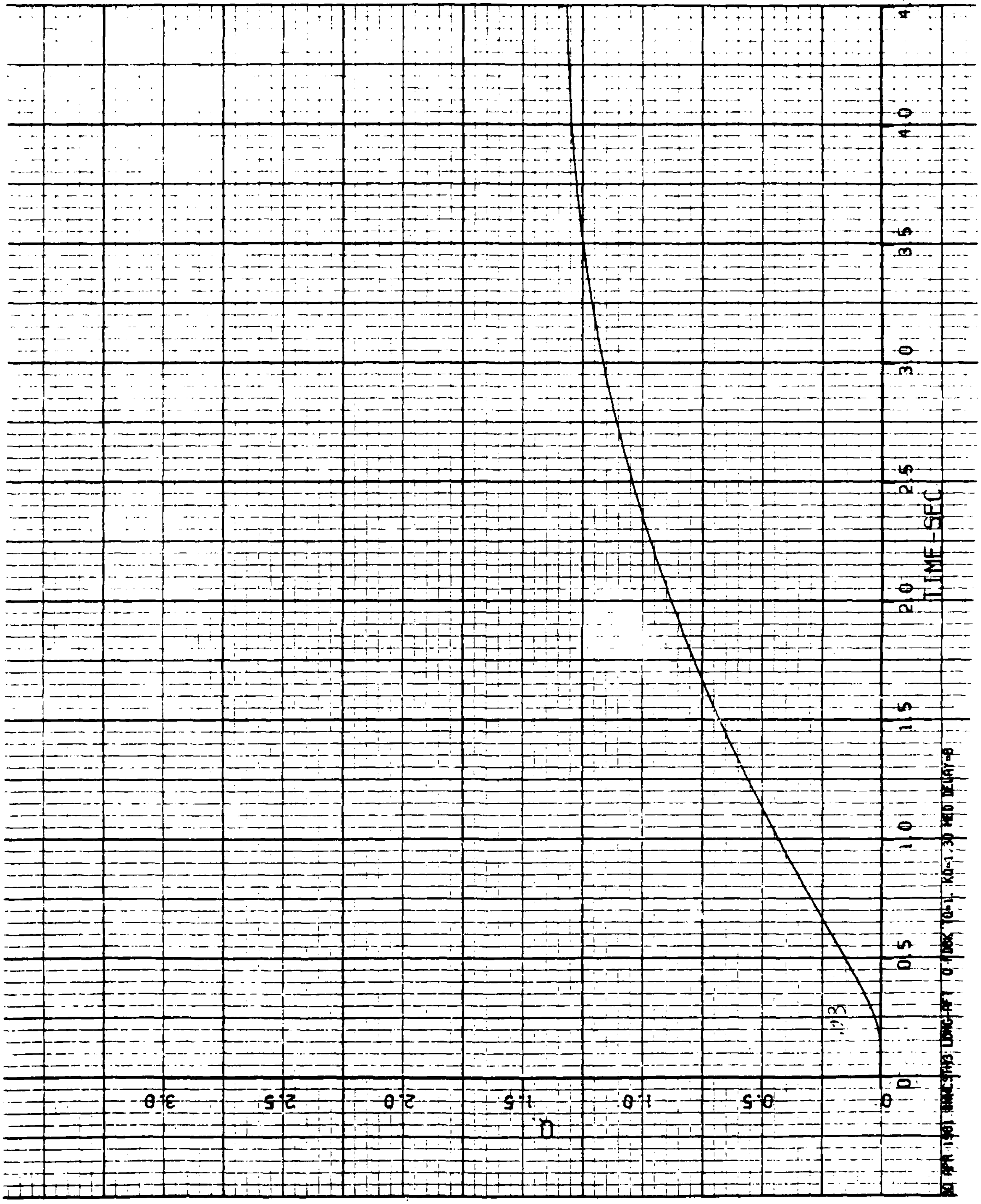
2.5
3.0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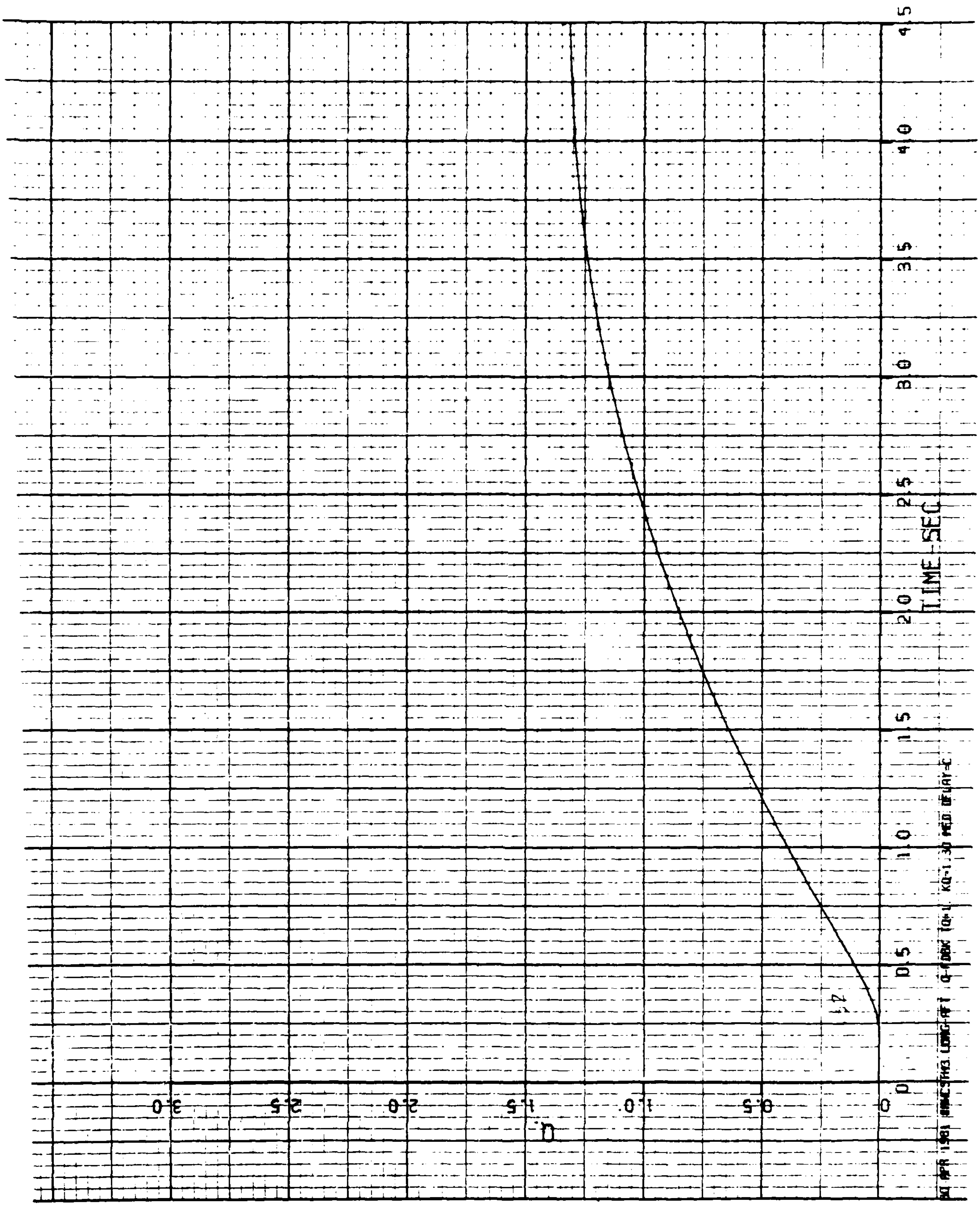
4.5
Q



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2.0
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3.0
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1.5
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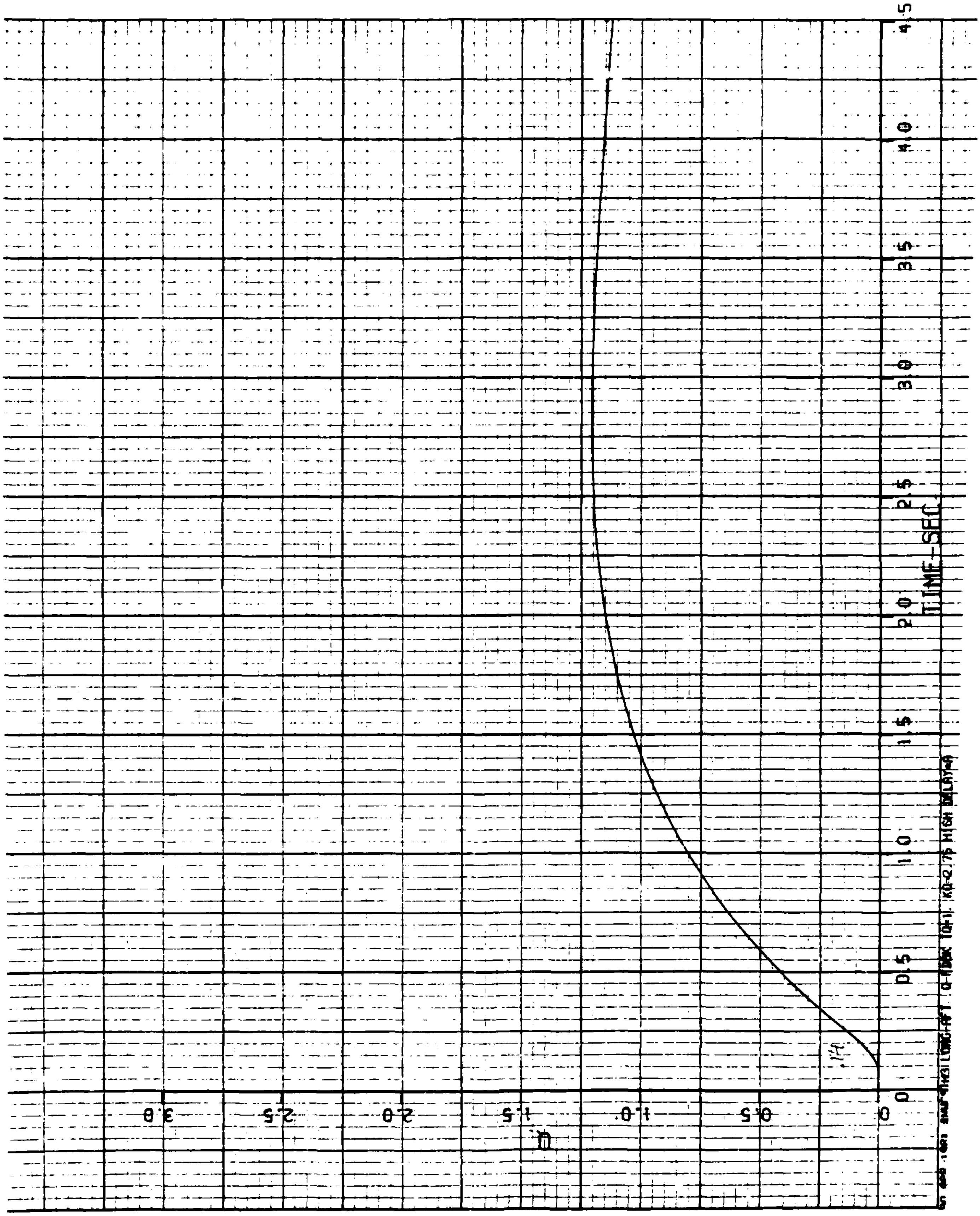
2.5
3.0
Q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1.0
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2.0
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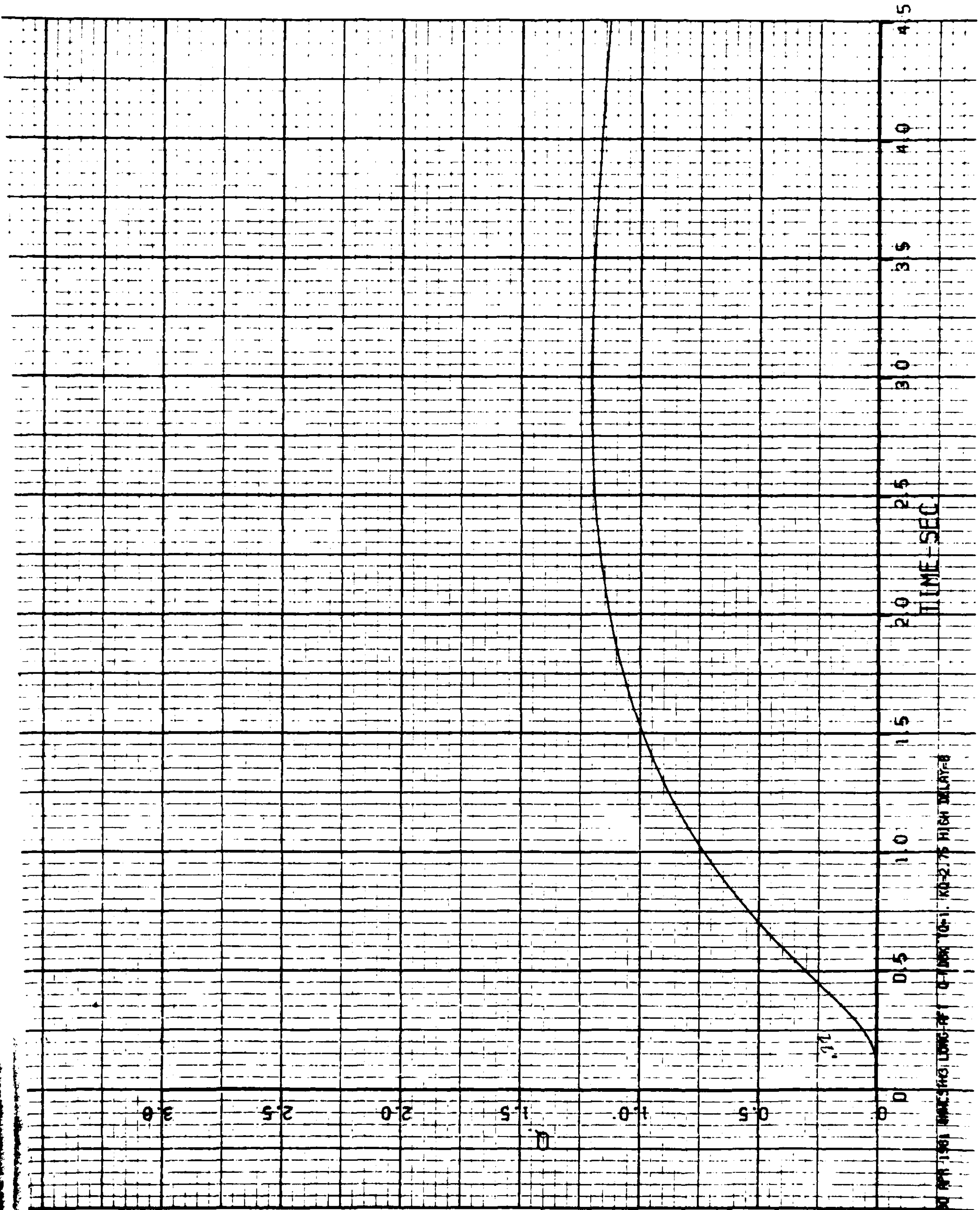
3.0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1.5
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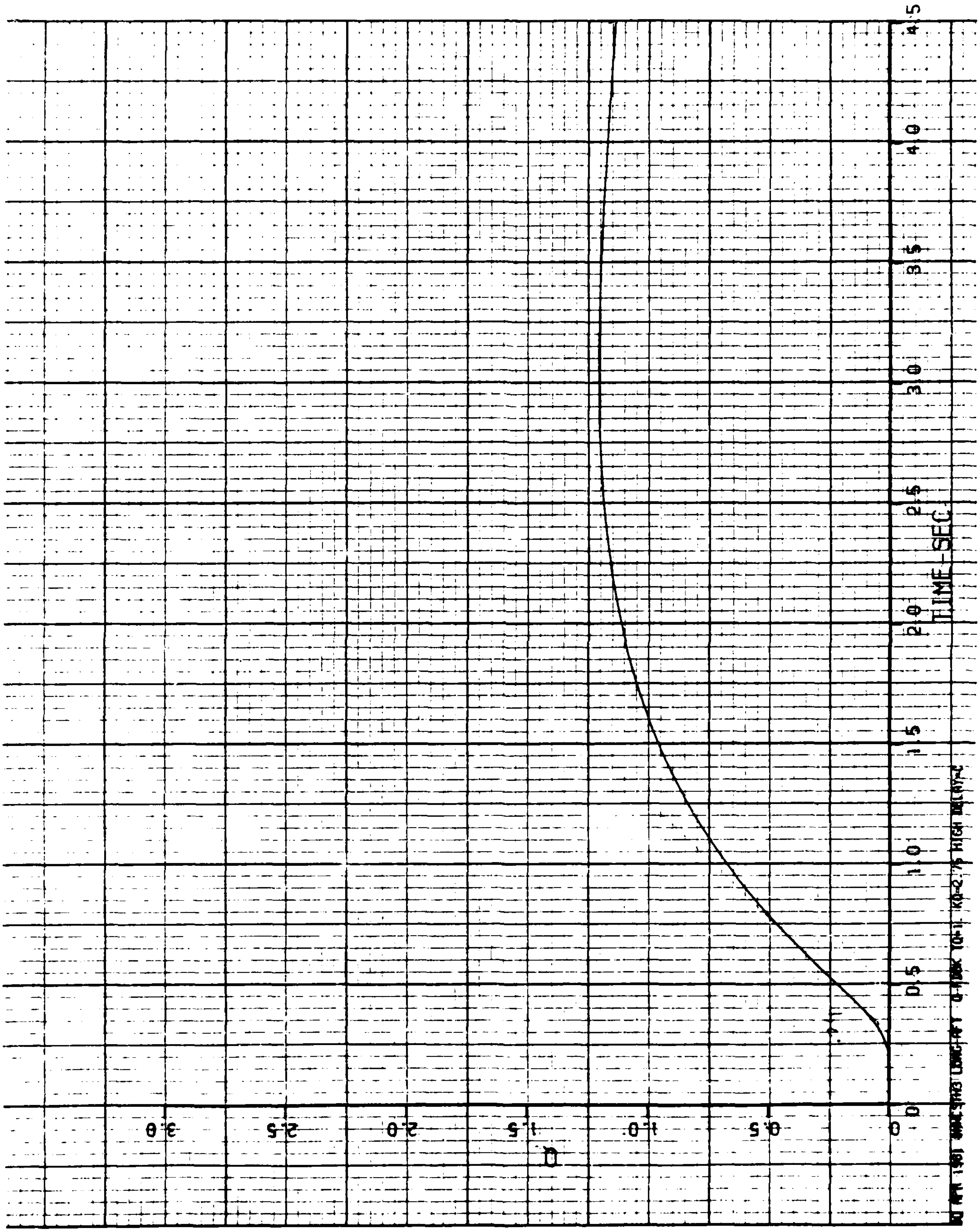
3.5
4.0
4.5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Q
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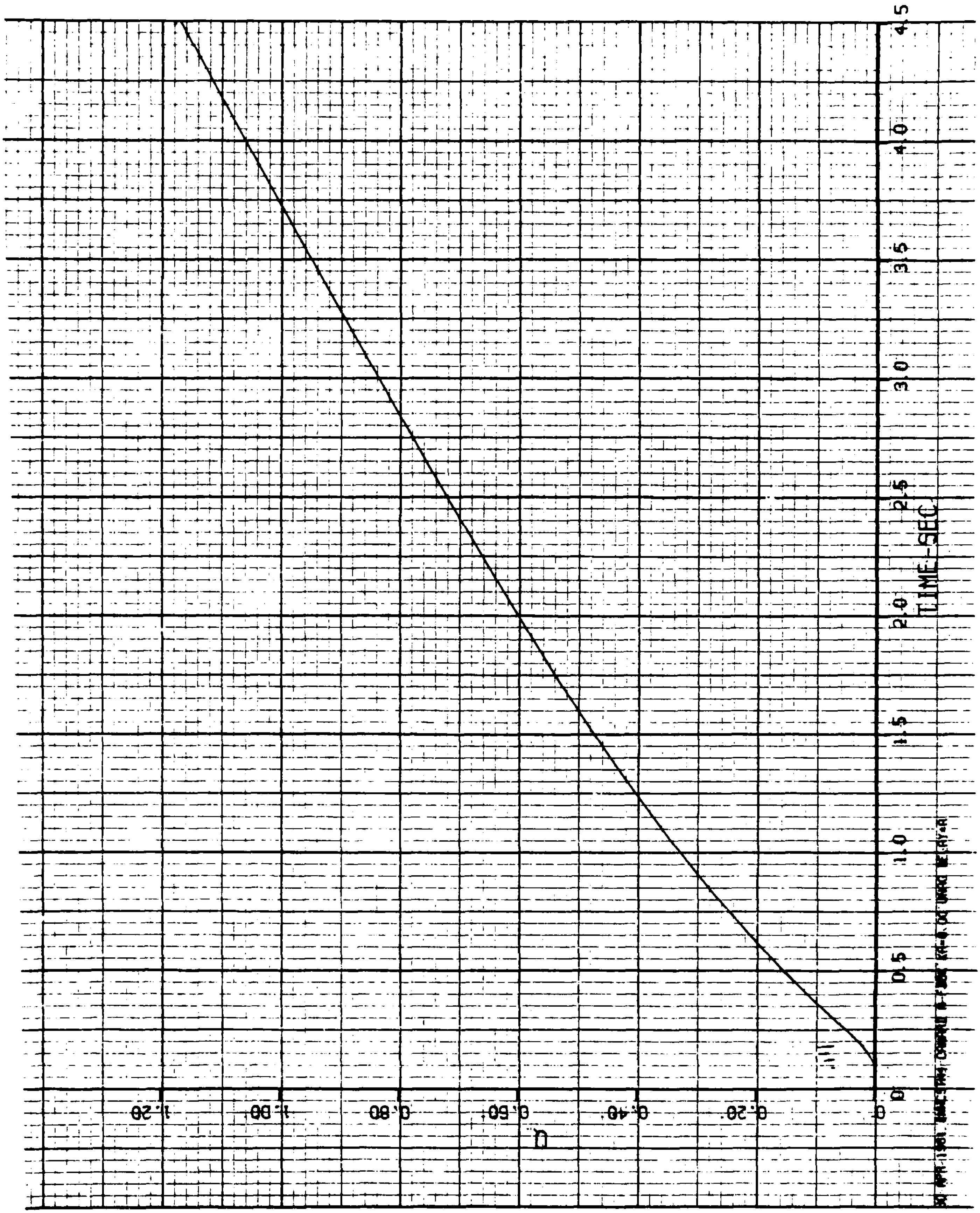
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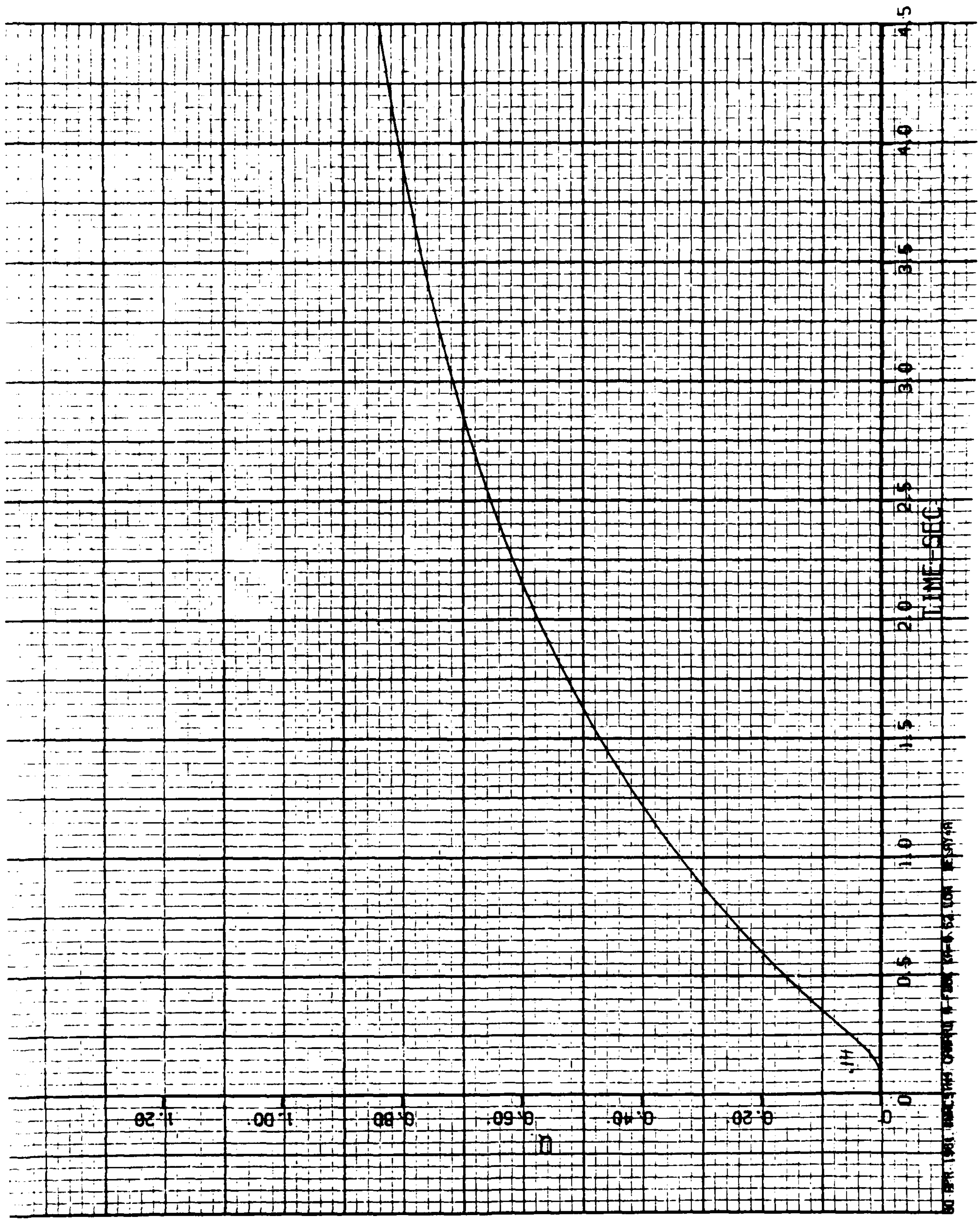
0.40
0.60
0.80
1.00
1.20


TIME-SEC
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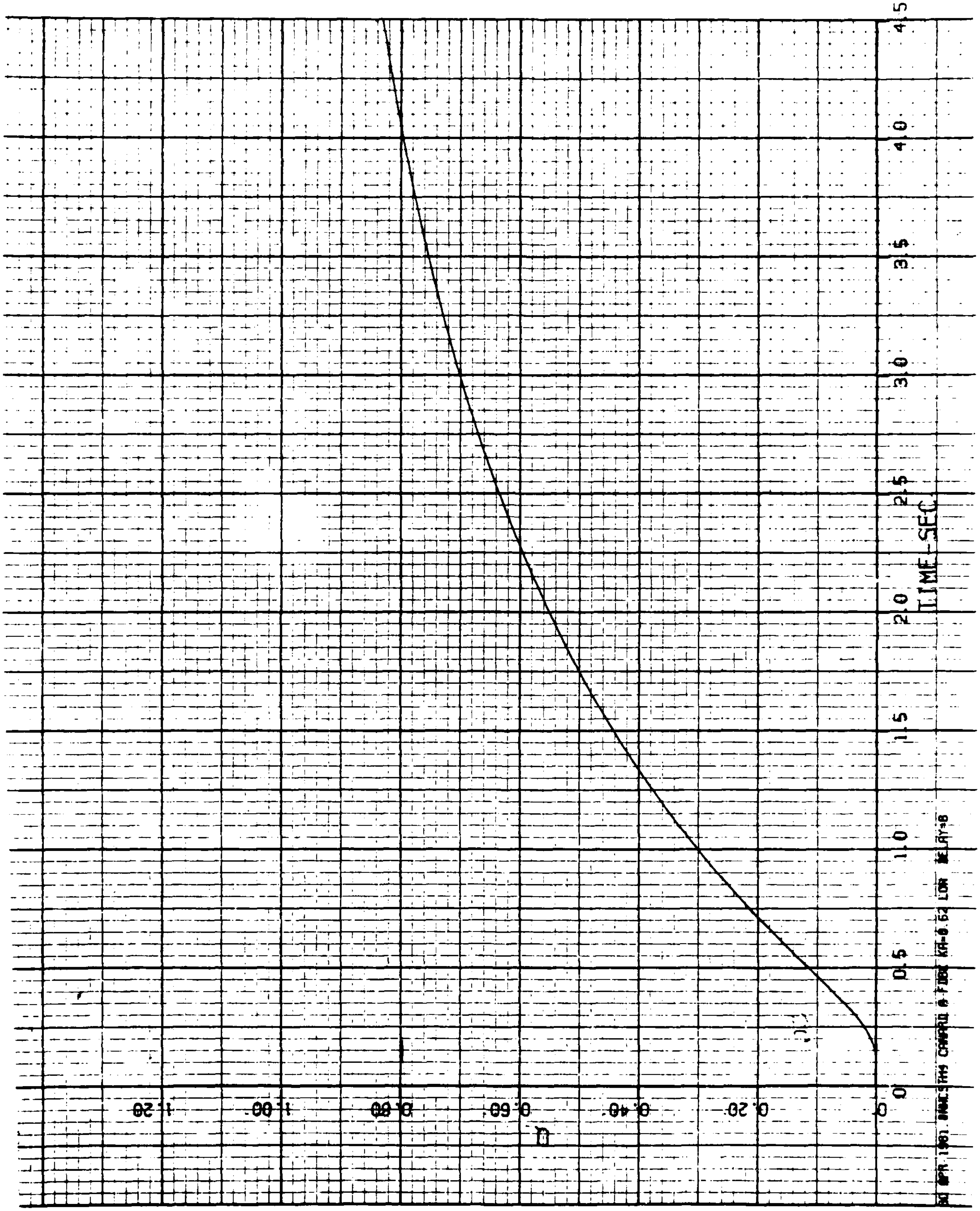
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
0.20
0.40
0.60
0.80
1.00
1.20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1.5
2.0
2.5
3.0
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4.5
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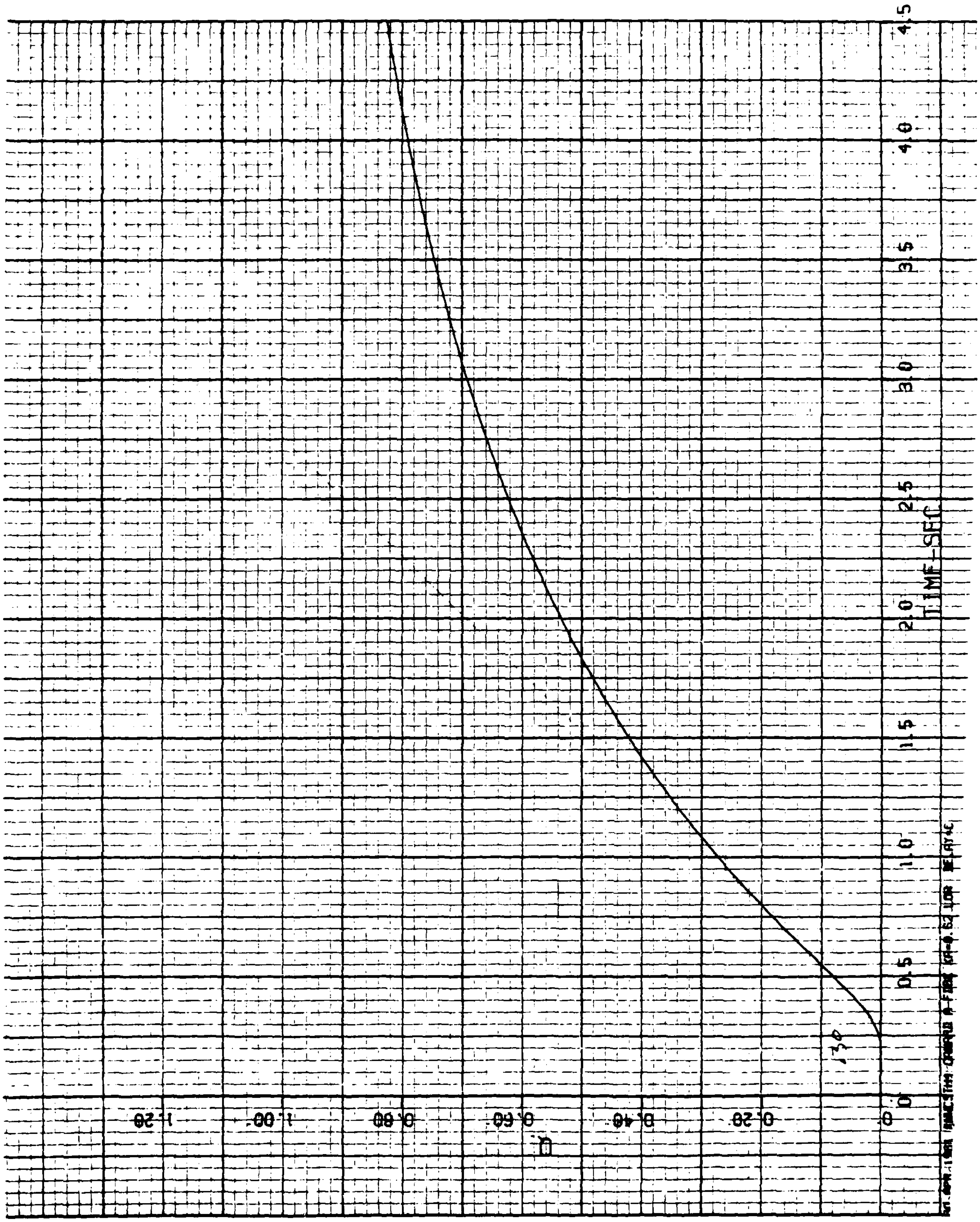
0.40
0.60
0.80
1.00
1.20
KA=0.52 LOW



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4.5
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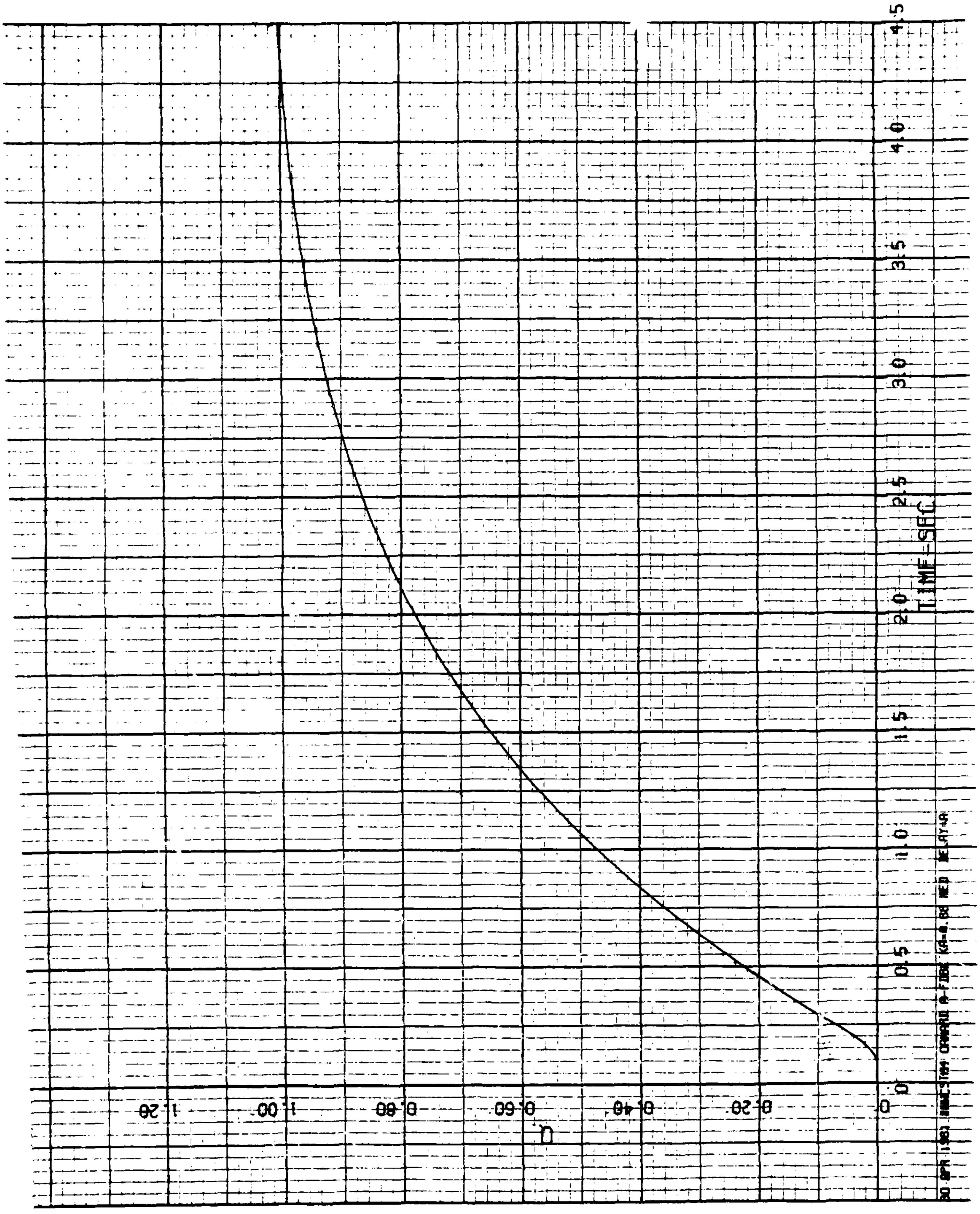
1.20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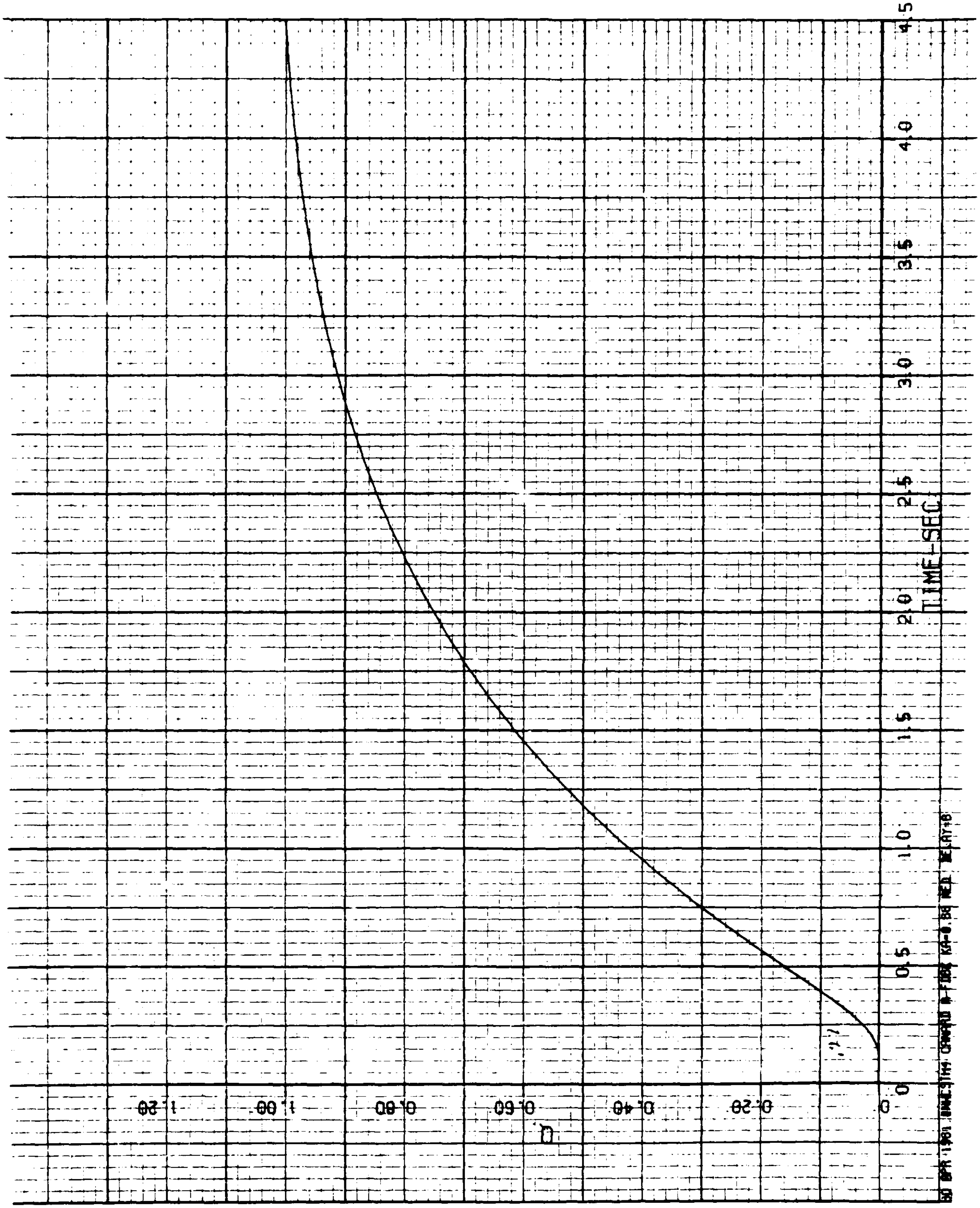
0.40
0.60
0.80
1.00
1.20



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1.0
1.5
2.0
2.5
3.0
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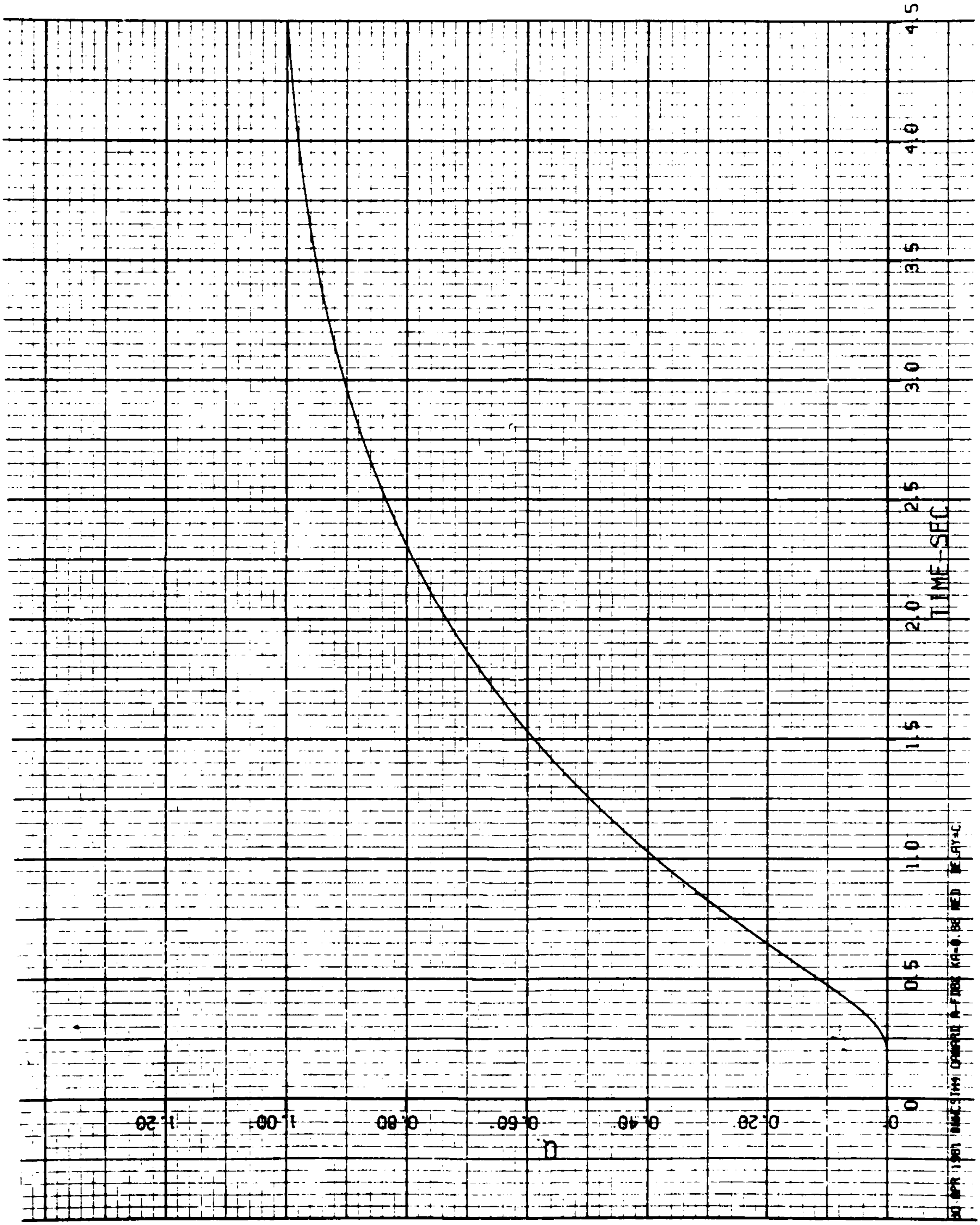
0.40
0.60
0.80
1.00
1.20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2.0
2.5
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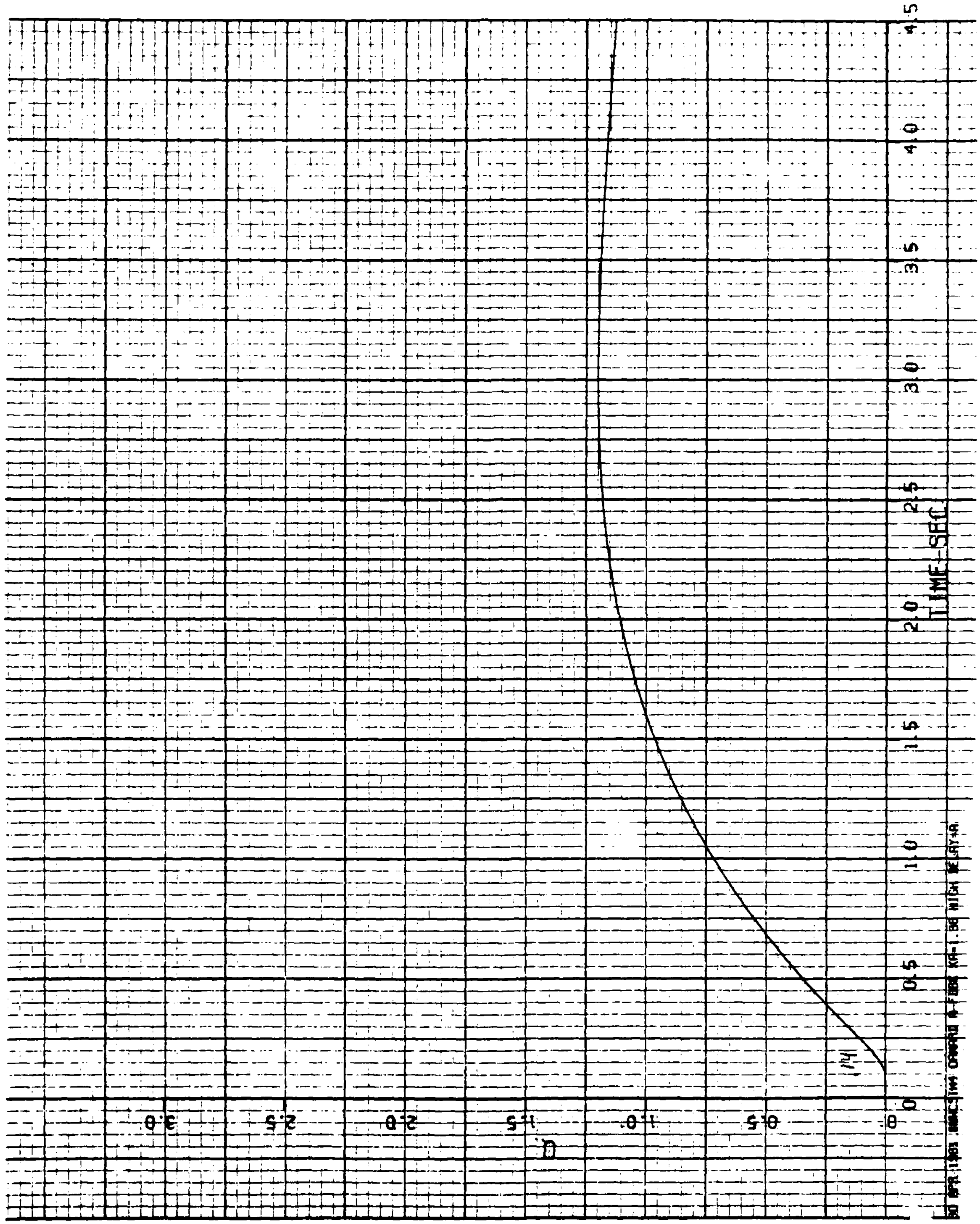
0.40
0.60
0.80
1.00
1.20



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4.5
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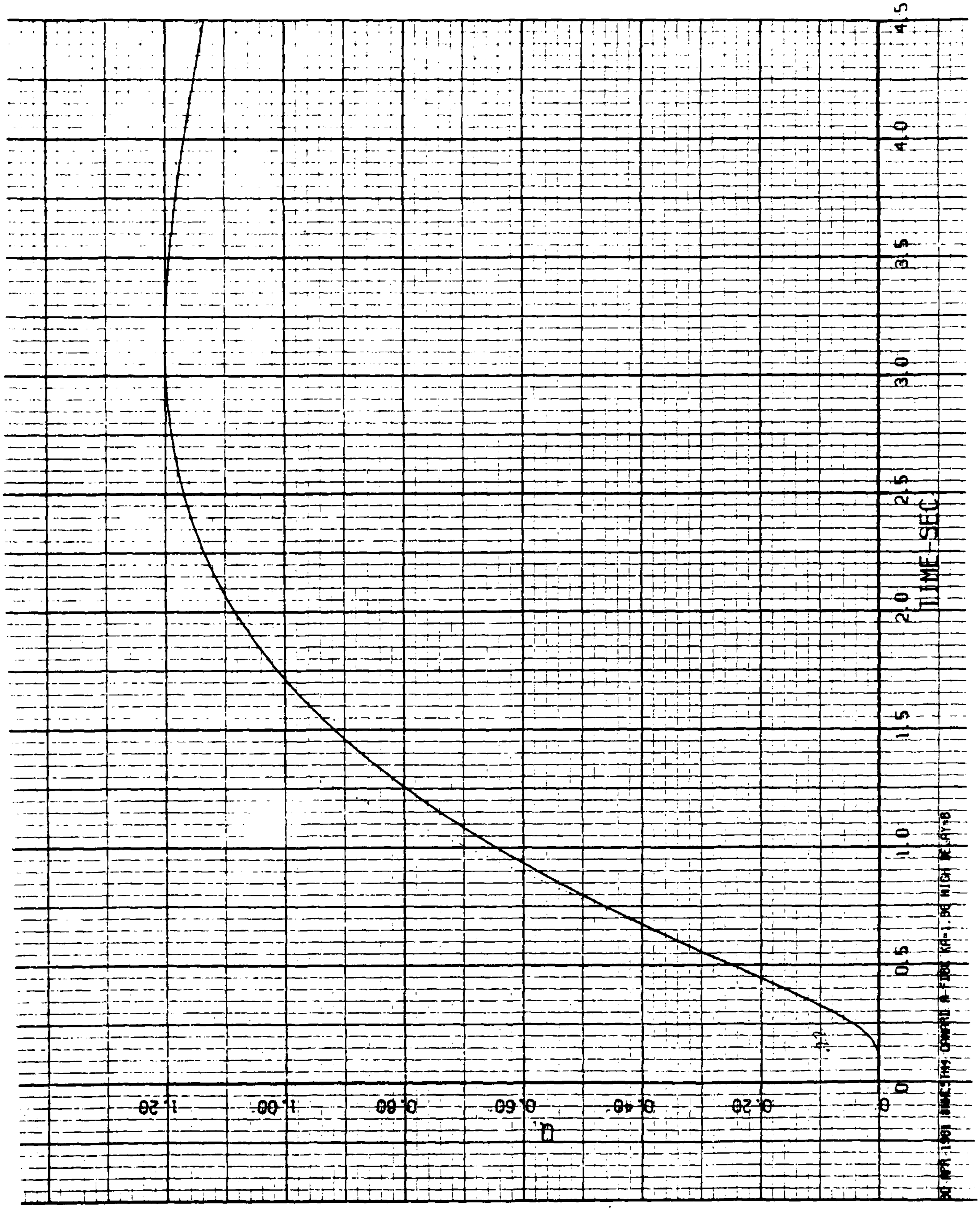
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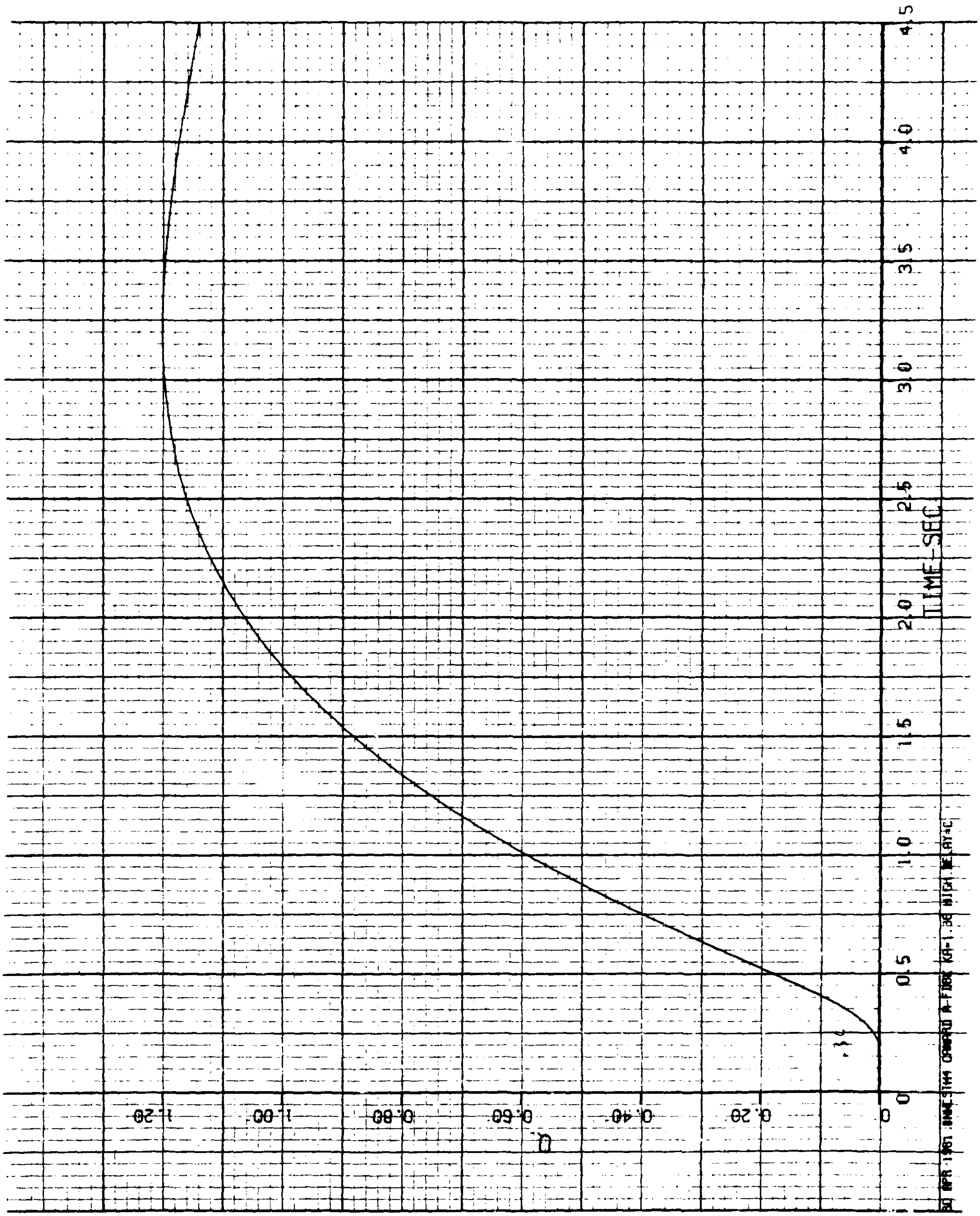
0.80
1.00
1.20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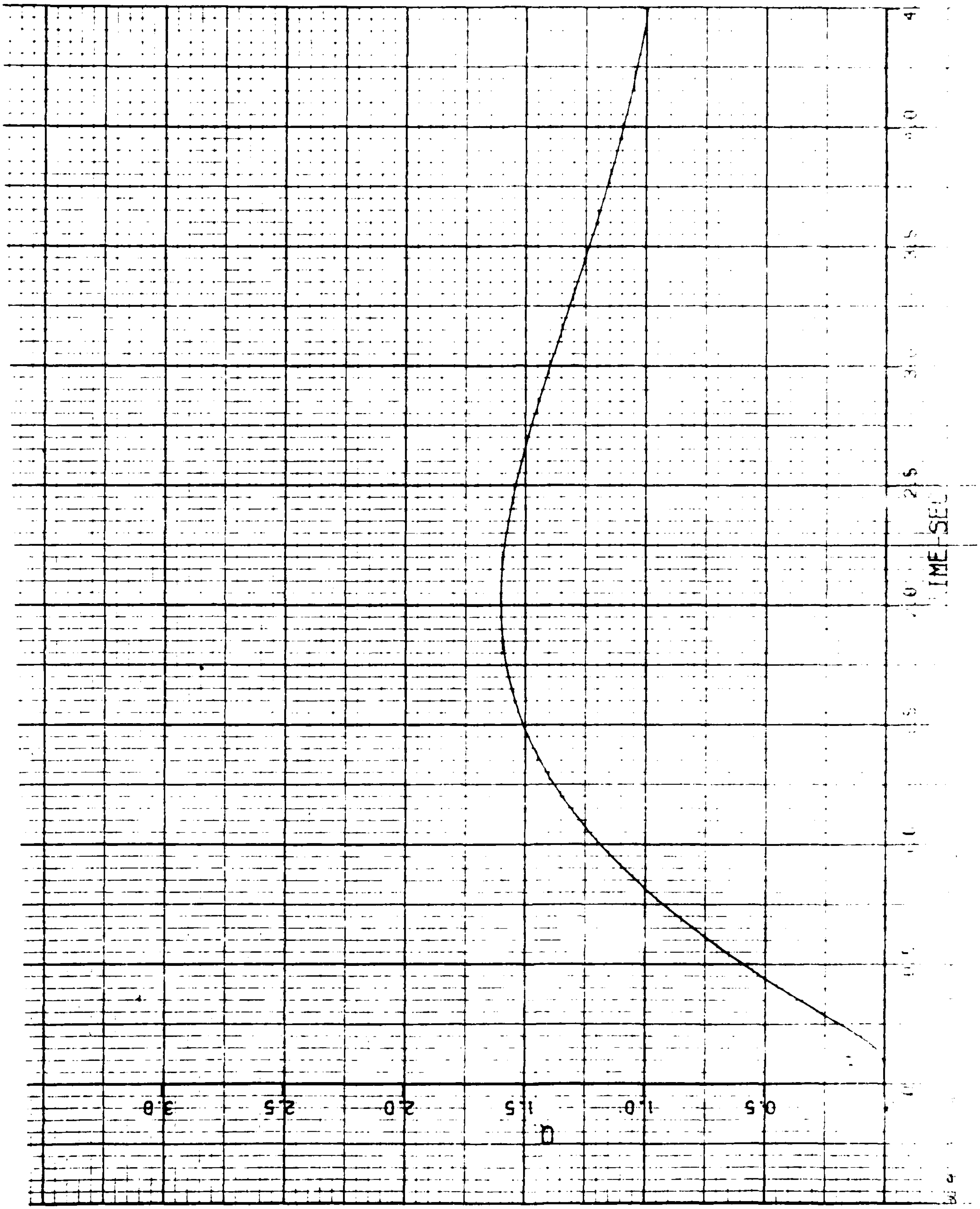
0.80
1.00
1.20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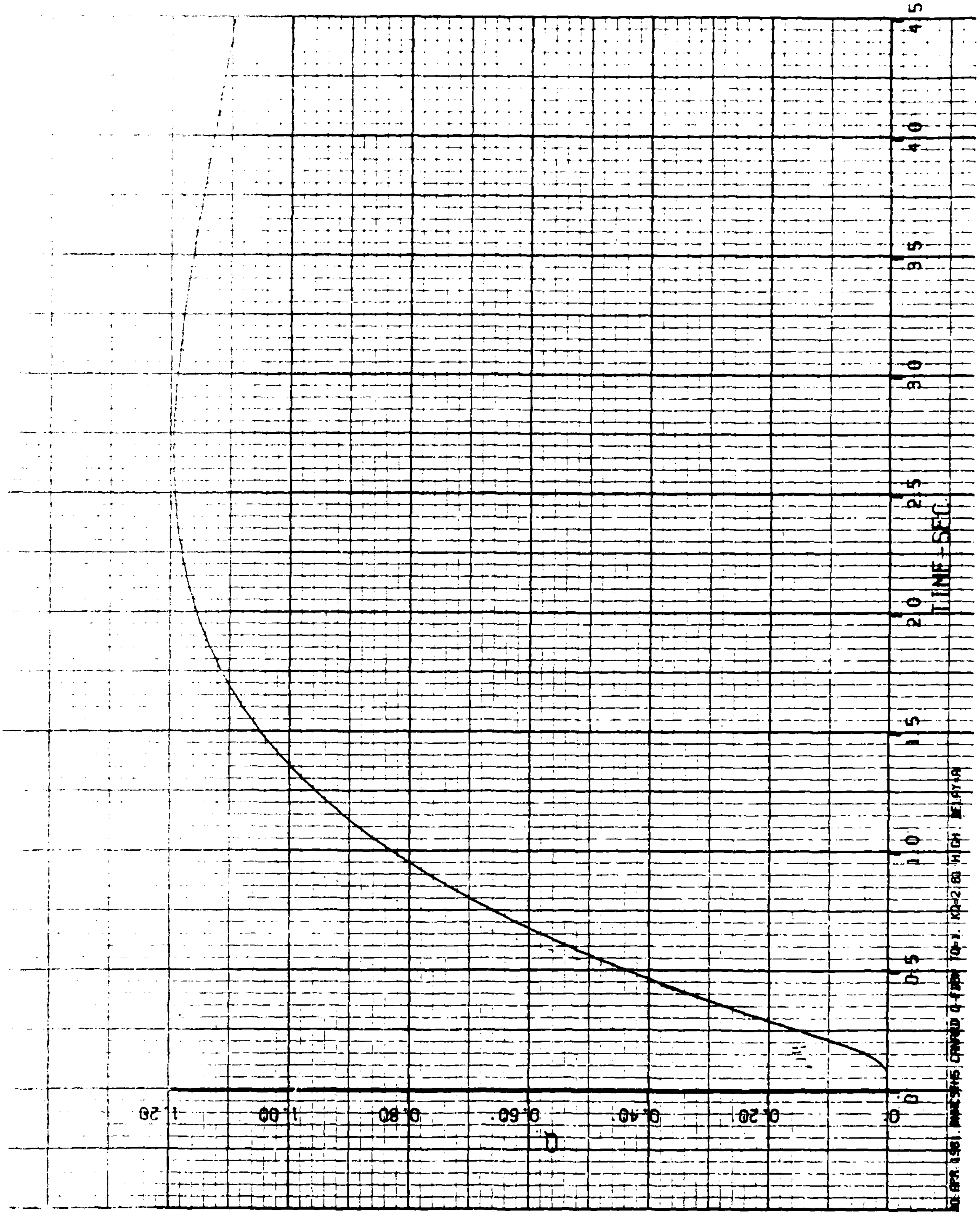
1.0
1.5
2.0
2.5
3.0
Q
2.5
IME-SEC


TIME - SEC
0
05
10
15
20
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30
35
40
45
Q
0
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0.40
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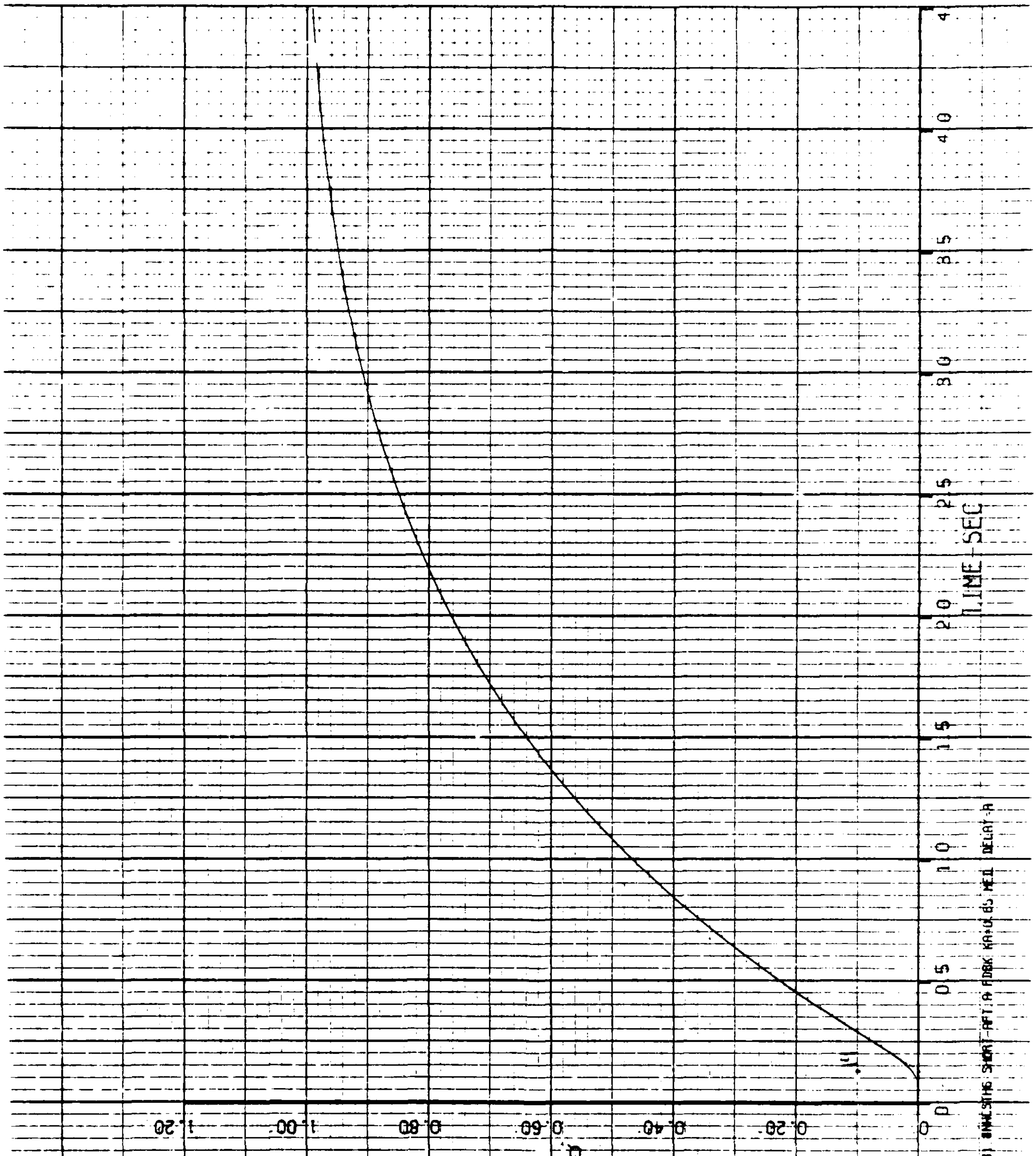
1.00
1.20



TIME-SEC
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10
15
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25
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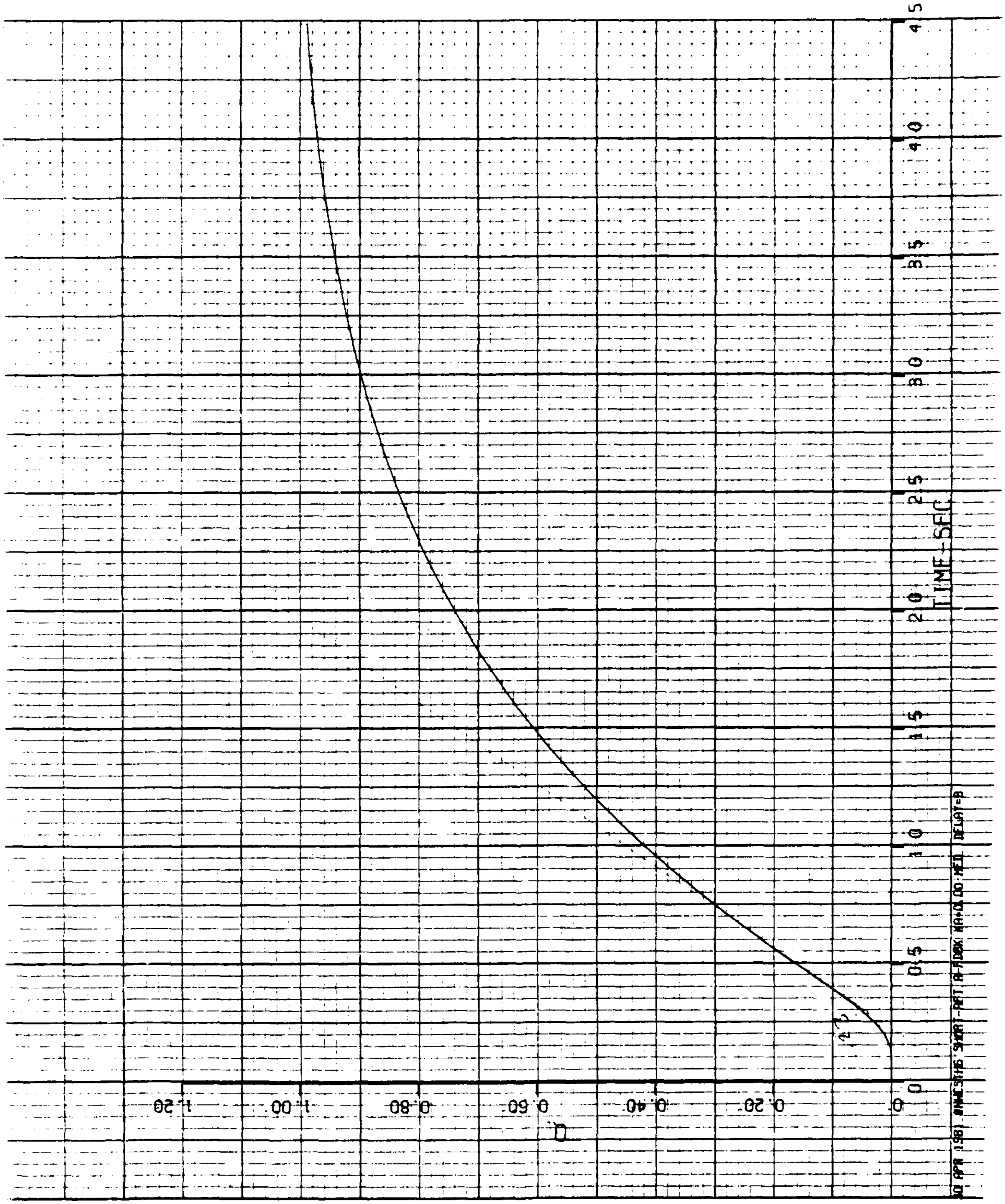
35
40
45
0
0.20
0.40
0.60
0.80
1.00
1.20
D
DELAY-A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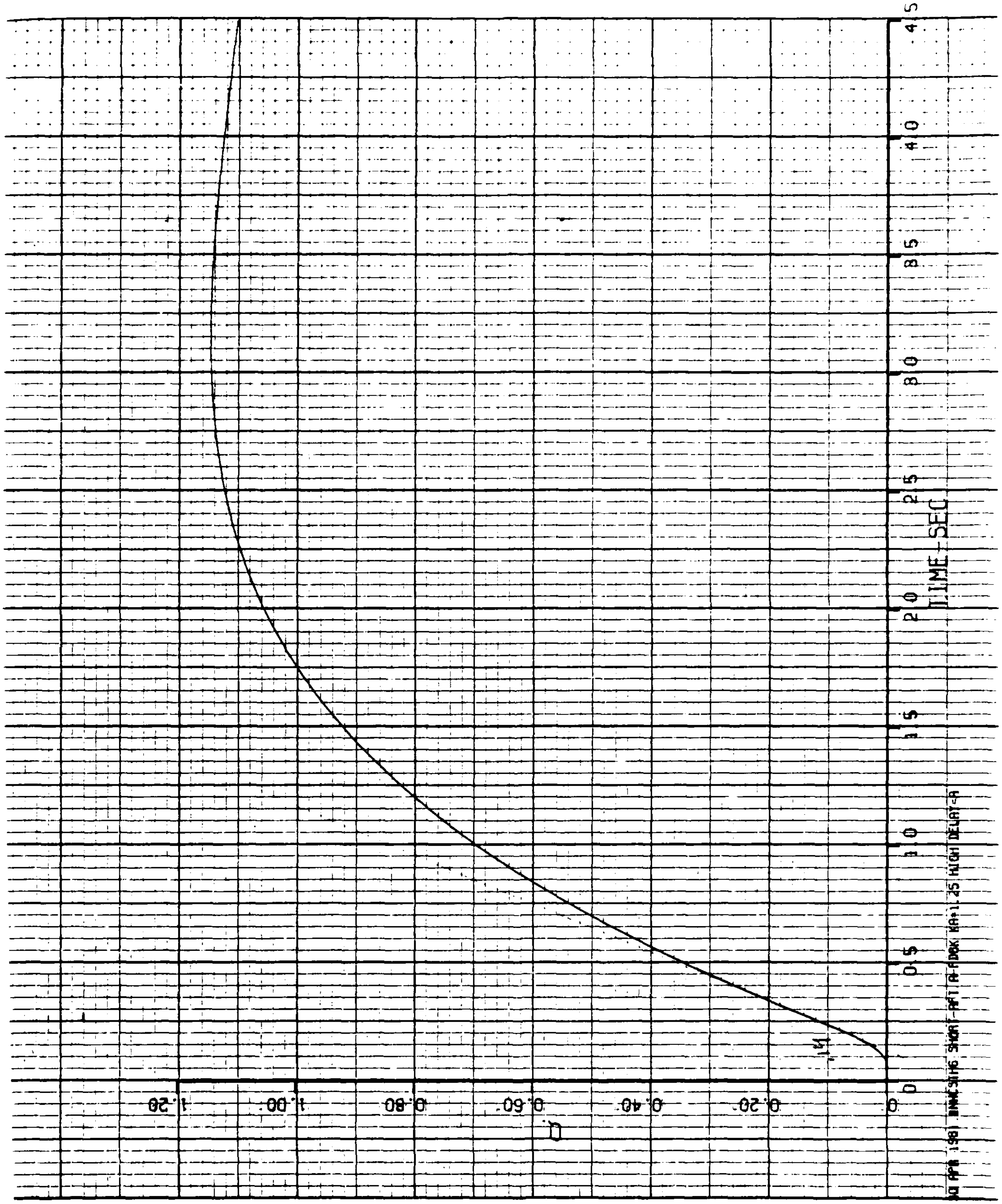
0.40
0.60
0.80
1.00
1.20



TIME-SEC
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1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
0
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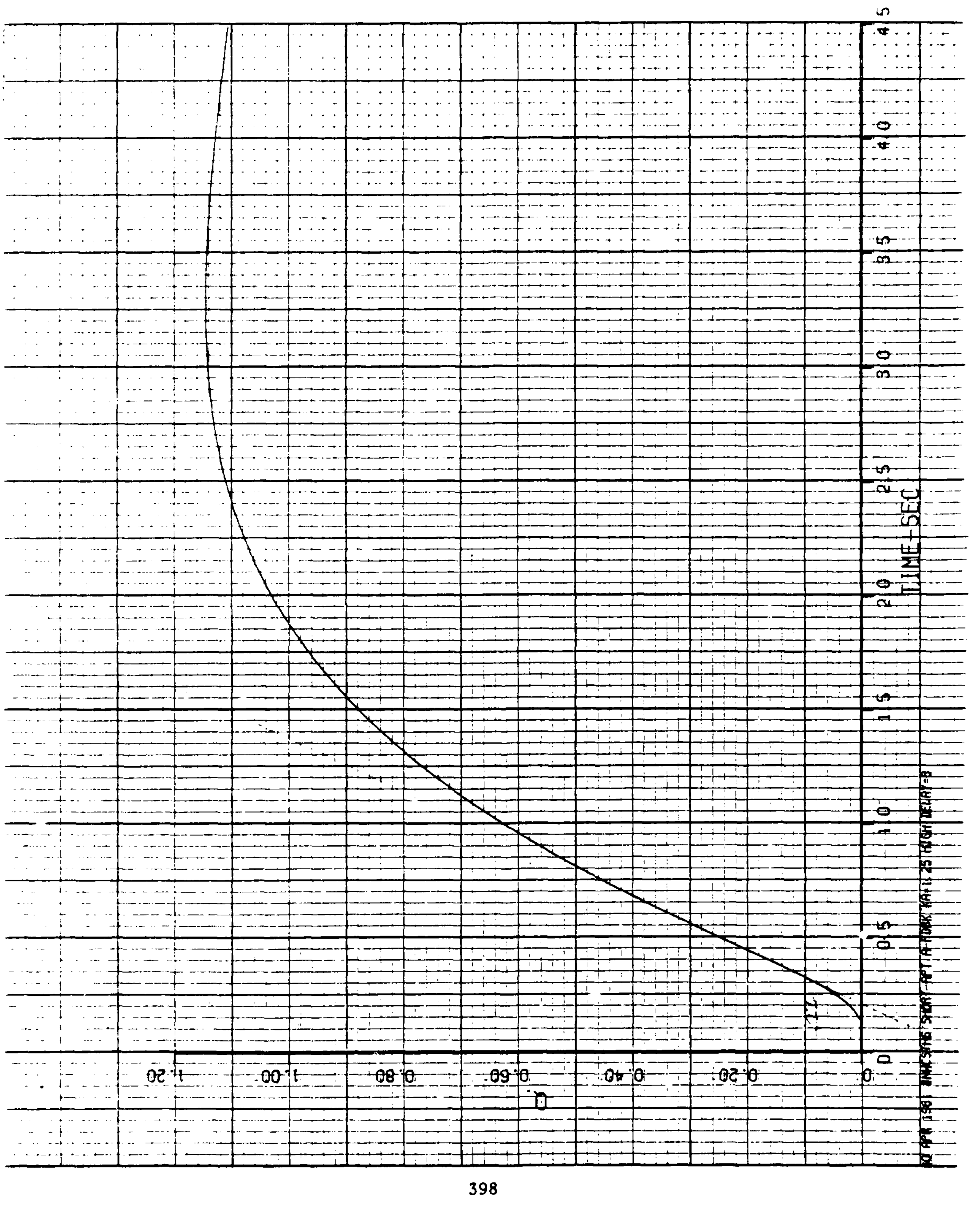
0.40
0.60
0.80
1.00
1.20
14



TIME-SEC
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0
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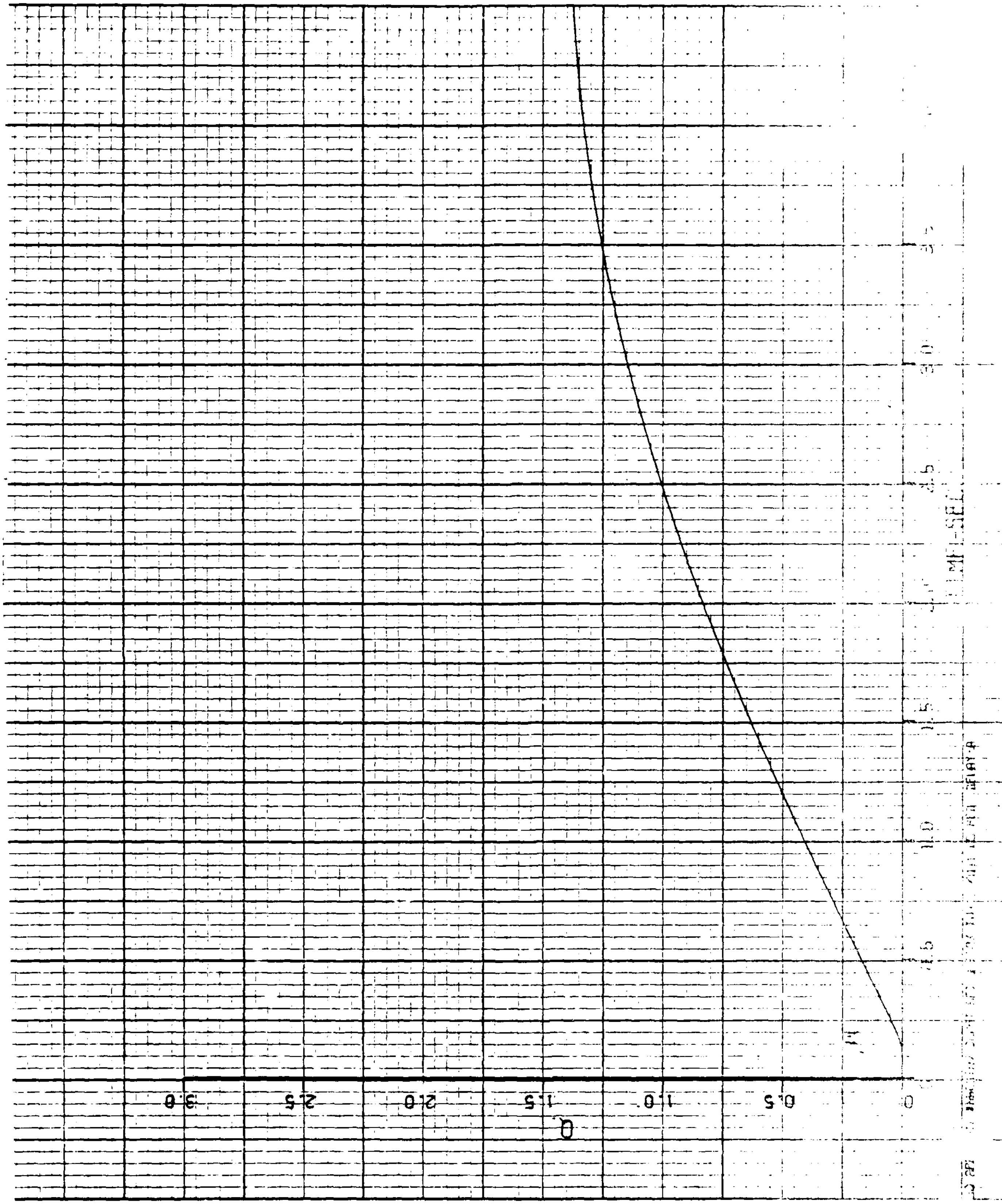
1.00
1.20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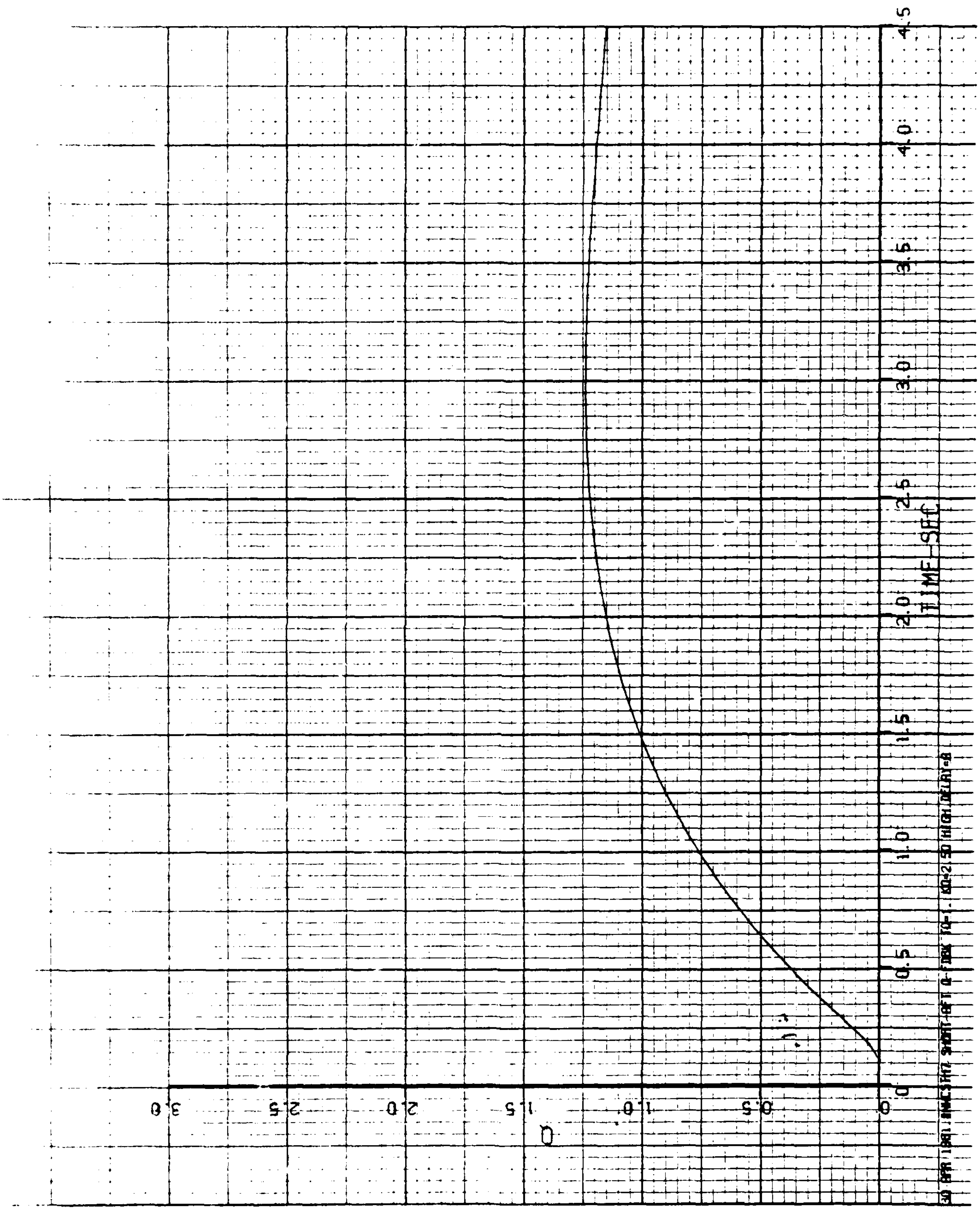
2.5
3.0


0
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TIME-SEC
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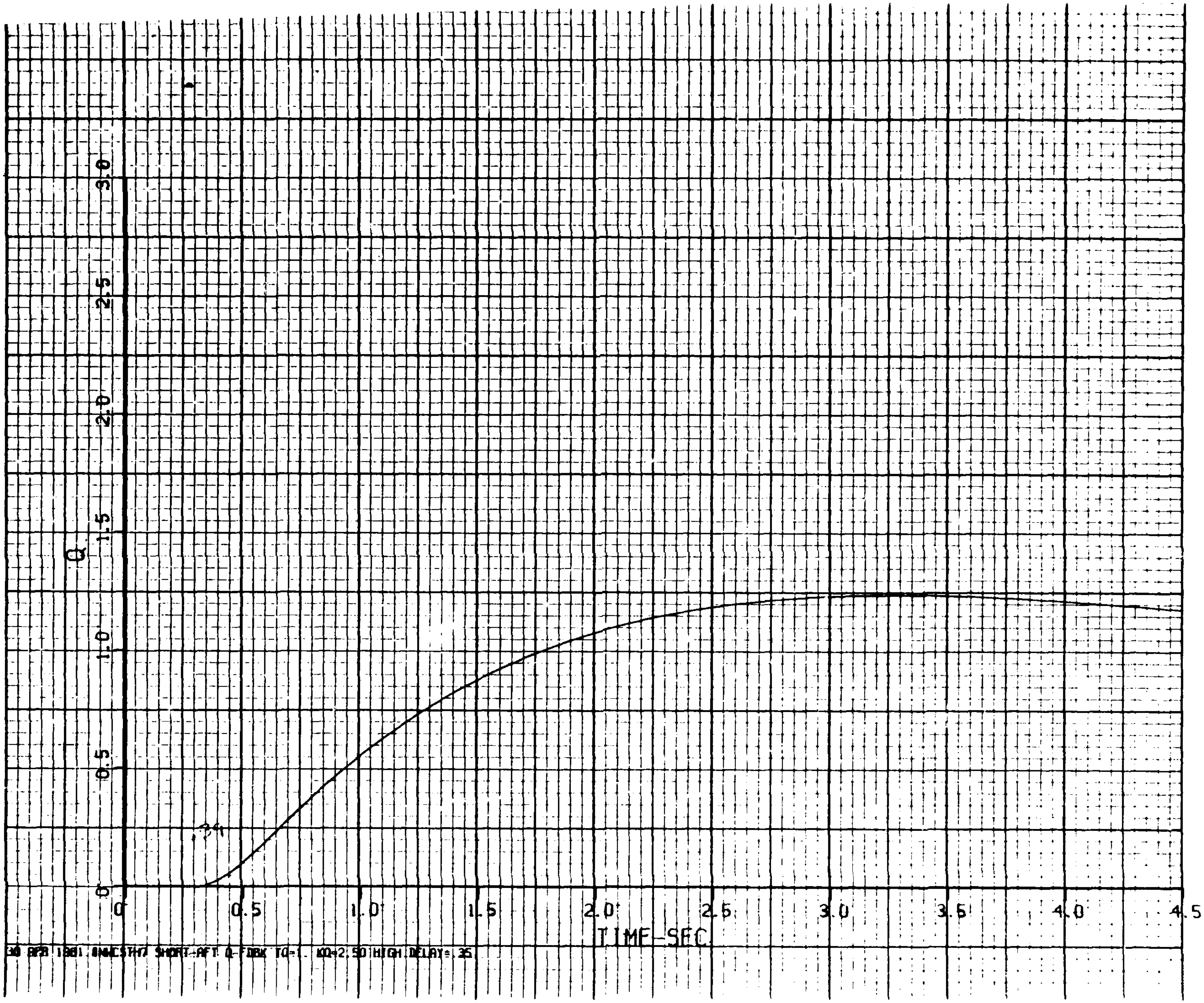
1.0
1.5
2.0
2.5
3.0
Q


Q
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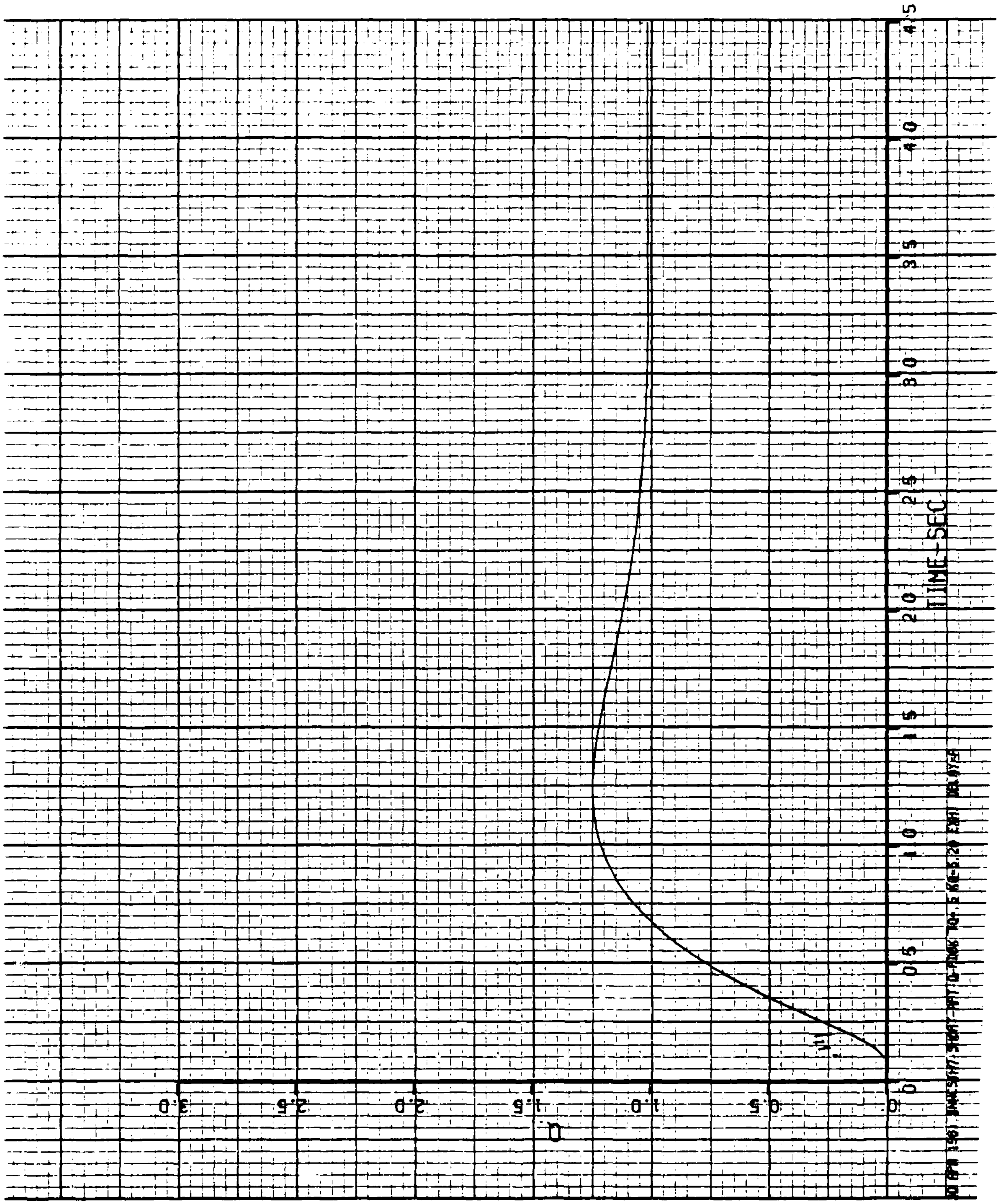
1.0
1.5
2.0
2.5
3.0
0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
TIME-SEC
.34
30 APR 1981
SHORT-AFT Q-FDBK TQ=1. KQ=2.50 HIGH DELAY=.35


TIME-SEC
0
0.5
1.0
1.5
2.0
2.5
3.0
Q

Appendix V-C

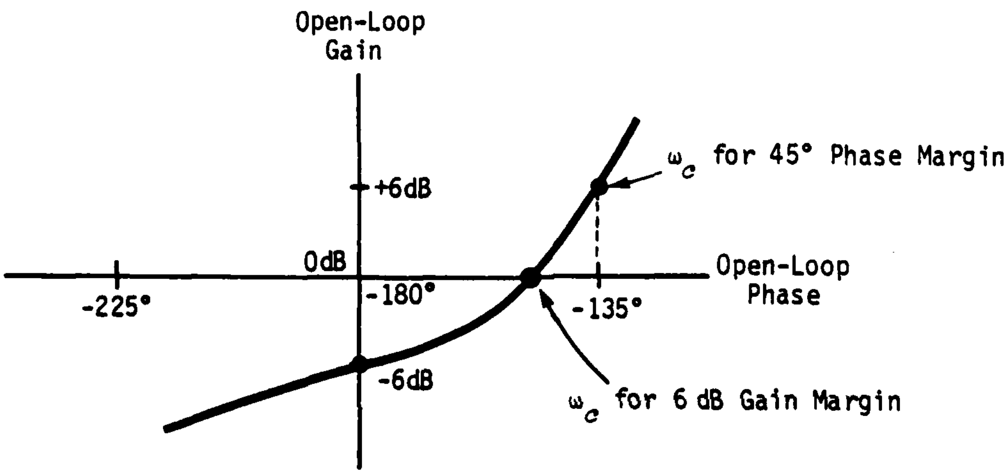
OPEN-LOOP (AIRCRAFT ONLY) PITCH ATTITUDE ANALYSIS

In this analysis the open-loop, aircraft-only, pitch attitude bandwidth was obtained and combined with equivalent time delay for correlation with pilot ratings and comments. This is the bandwidth criterion suggested by STI in Reference 7 where bandwidth is defined as the lower of the frequencies which yields a 6 dB gain margin or 45 deg. phase margin. To easily obtain these values for each configuration, the aircraft's open-loop pitch attitude to stick force transfer function (θ/F_{ES}) was plotted on a Nichols diagram.

The frequency for 6 dB gain margin was obtained by shifting the curve vertically so that it went through -180 deg. phase angle with a magnitude of -6 dB. Then the frequency at which this shifted curve passed through 0 dB was measured. This crossover frequency was the bandwidth based on the gain margin.

The frequency for 45 deg. phase margin was obtained by measuring the frequency at which the curve passed through -135 degrees open-loop phase angle.

This procedure is shown in the following sketch:



A tabulation of the results of these measurements is presented in Table V-C-1. For all of the configurations except one (Long Aft Tail, low q, $T_1 = C$) the bandwidth was determined by the frequency at 45 deg phase margin. Plots of equivalent time delay (T_D) from the equivalent system analysis (Appendix V-A) versus these calculated open-loop bandwidths are presented in Figures V-C-1 through V-C-4. Pilot ratings for the individual configurations evaluated are pointed out on these plots. Also plotted are the Level 2 and 3 boundaries from Reference 7 for fighter landing approach data.

TABLE V-C-1

OPEN-LOOP BANDWIDTH (RAD/SEC) FOR θ/F_{ES}

FREQUENCIES FOR 6 dB GAIN MARGIN AND 45° PHASE MARGIN

Open-Loop Bandwidth Defined as Lower of the Two Values

CONFIGURATION		LEVEL OF DELAY (T_1)					
		A		B		C	
		6 dB GM	45° PM	6 dB GM	45° PM	6 dB GM	45° PM
Long Aft Tail	Unaug.	1.10	.22			.65	.21
	Low α gain	1.25	.40	.93	.36	.83	.35
	Med α	1.30	.60	1.0	.54	.90	.51
	High α	1.40	.81	1.1	.75	.98	.71
	Ex-High α	1.55	1.07				
	$N_z/\alpha = 3$	1.41	.89				
	$N_z/\alpha = 2$	1.45	.97				
	Low q gain	.36	.35			.23*	.33
	Med q	.85	.53	.70	.51	.63	.50
	High q	1.58	.89	1.23	.81	1.07	.77
Canard	Unaug.	1.20	.23				
	Low α	1.29	.41	.95	.38	.83	.36
	Med α	1.32	.58	1.0	.53	.88	.50
	High α	1.37	.80	1.06	.73	.96	.70
	Ex-High α	1.48	1.08				
	High q	1.62	.93				

*Only case where 6 dBGM resulted in lower ω_c.

TABLE V-C-1 (CONT'D)

OPEN-LOOP BANDWIDTH (RAD/SEC) FOR θ/F_{ES}

FREQUENCIES FOR 6 dB GAIN MARGIN AND 45° PHASE MARGIN

Open-Loop Bandwidth Defined as Lower of the Two Values

CONFIGURATION	LEVEL OF DELAY (T_1)					
	A		B		C	
	6 dB GM	45° PM	6 dB GM	45° PM	6 dB GM	45° PM
<u>Short Aft Tail</u> Med α gain	1.35	.57	1.0	.52		
High α	1.42	.80	1.1	.73		
Med q	.61	.47				
High q gain	1.43	.82			(.85	.68)*
Ex-High q	1.84	1.68				

*T_1 = .35 (shuttle lags/delay)

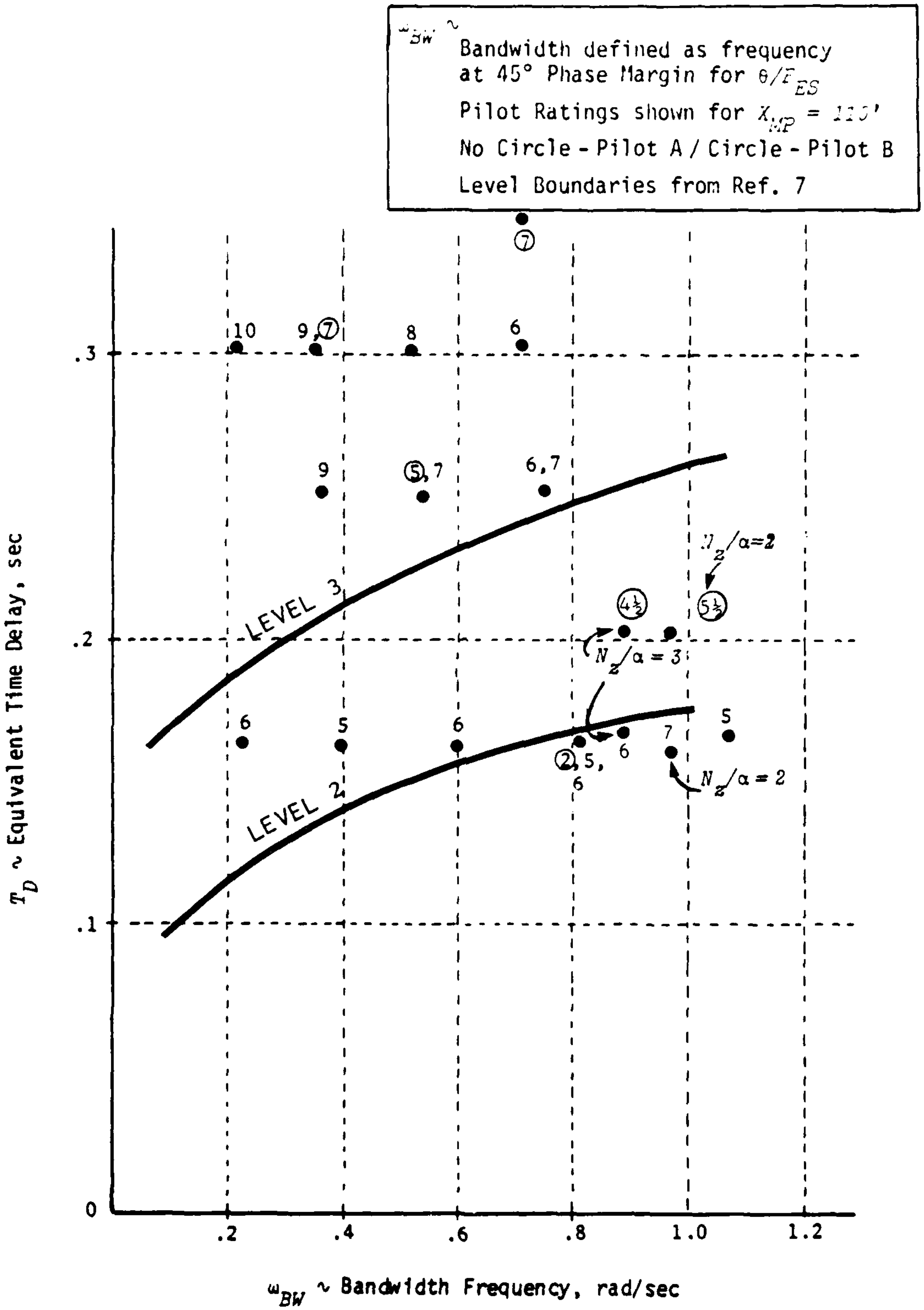


Figure V-C-1. LONG AFT TAIL α- FEEDBACK OPEN LOOP θ/F_{ES} BANDWIDTH VS TIME DELAY

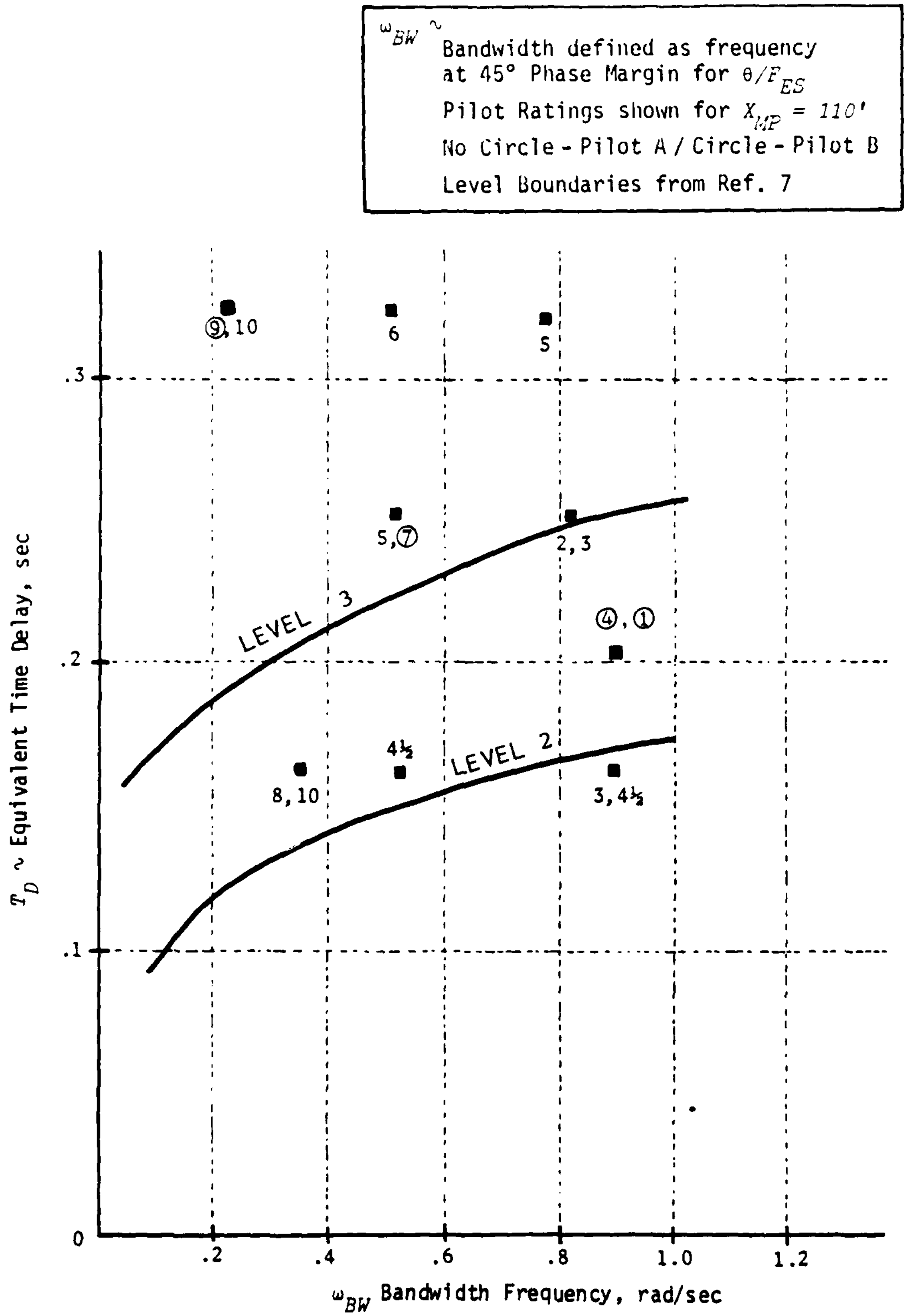


Figure V-C-2. LONG AFT TAIL q- FEEDBACK OPEN LOOP θ/F_{ES} BANDWIDTH VS TIME DELAY

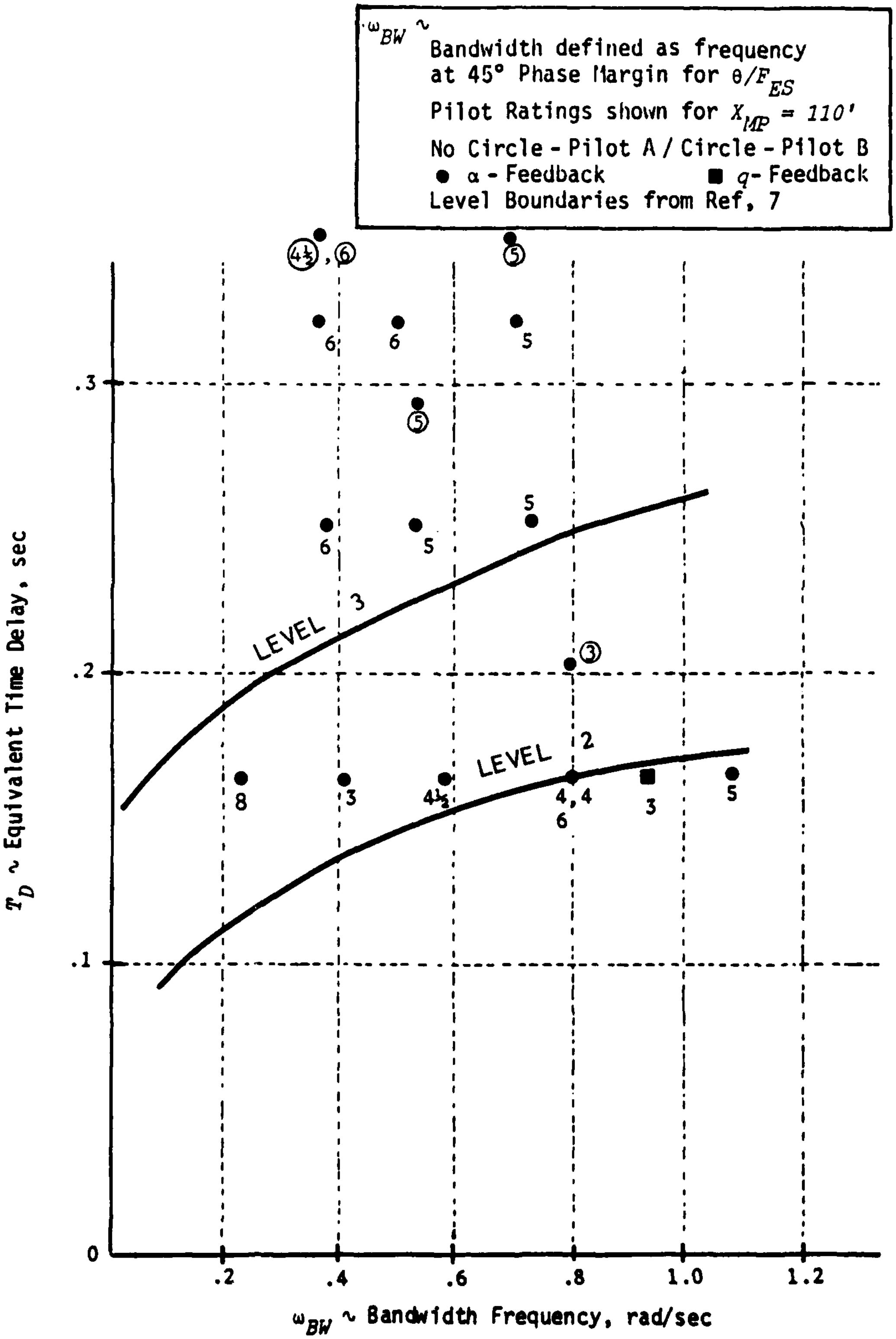


Figure V-C-3. CANARD OPEN LOOP θ/F_{ES} BANDWIDTH VS TIME DELAY

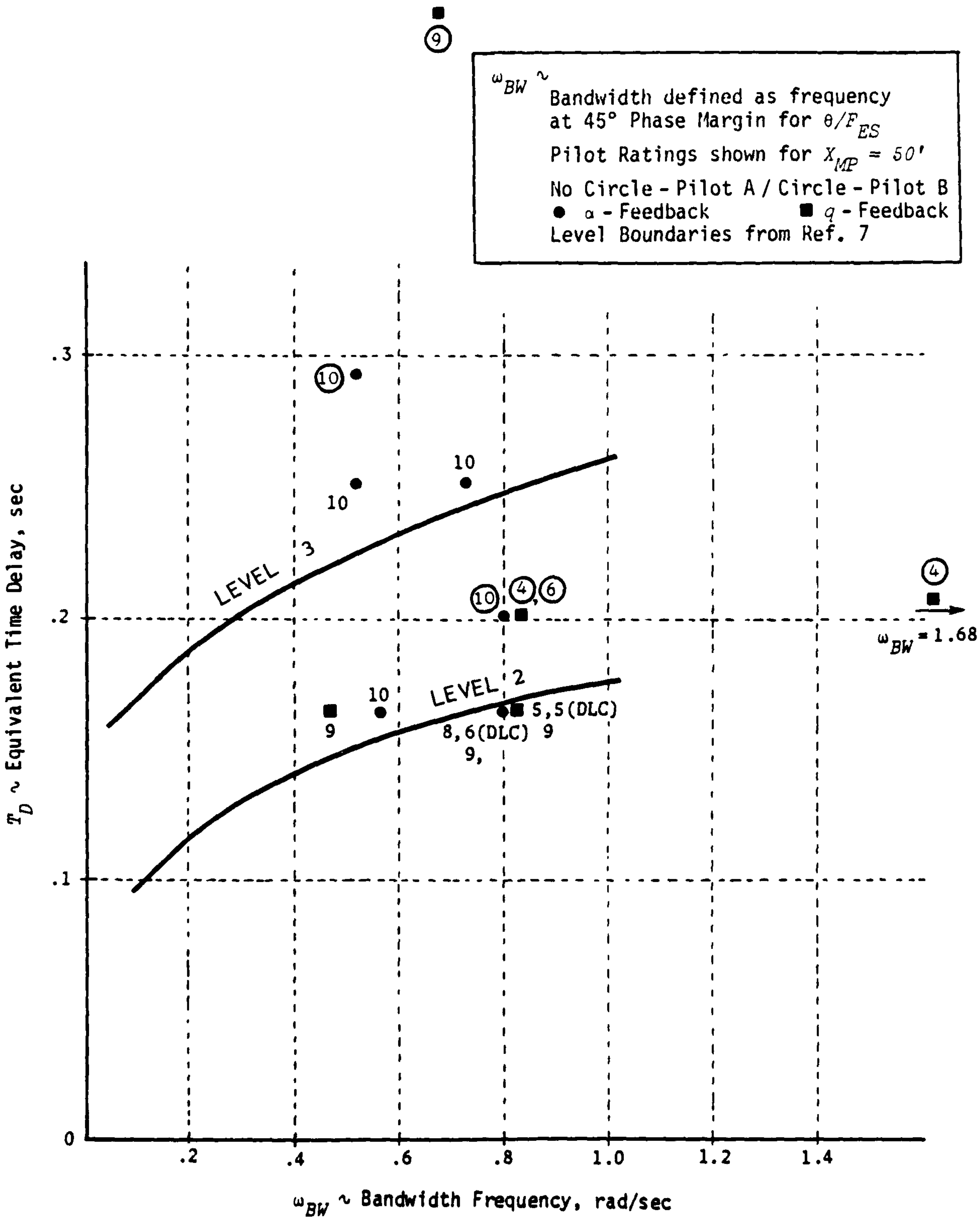


Figure V-C-4. SHORT AFT OPEN LOOP θ/F_{ES} BANDWIDTH VS TIME DELAY

Appendix V-D

OPEN-LOOP (AIRCRAFT PLUS UNCOMPENSATED PILOT) PITCH ATTITUDE ANALYSIS

A simplified method of analyzing the closed-loop, pilot-aircraft behavior that has been used to correlate pilot ratings was developed in Reference 5. In this method, only the airplane pitch attitude and uncompensated pilot model transfer functions are necessary. The open-loop, uncompensated pilot-aircraft transfer function ($\theta/\theta_\varepsilon$) is plotted on a Nichols diagram. The slope of this line, $\left(\frac{\Delta A}{\Delta \phi}\right)_\theta$, at some reference frequency is a measure of the closed-loop resonance. The more positive the slope becomes, the lower the closed-loop resonance will be. The differential phase angle $\Delta\phi_\theta$ between -90 deg and the phase angle at the reference frequency is a measure of the amount of lead compensation that the pilot must apply: the larger the differential phase angle, the larger the lead must be.

Nichols diagrams were obtained for each evaluated configuration with the uncompensated pilot model:

$$\theta/\theta_\varepsilon = Y_{P_\theta} \quad \theta/F_{ES}$$

(The 25 r/s feel system was used in this analysis).

$$Y_{P_\theta} = K_{P_\theta} \; e^{-.25s} \; \left(\frac{5s+1}{s}\right)$$

The transfer function was normalized by adjusting the gain K_{P_θ} such that the curves would pass through 0 dB at $\omega = 1$ rad/sec. (The measurements taken do not depend upon K_{P_θ}). A reference frequency was chosen as 1.2 rad/sec. These Nichols diagrams are presented at the end of this Appendix. A tabulation of the slope and phase measurements taken off of these plots is shown in Table V-D-1. These measurements are also plotted on Figures V-D-1 through V-D-4. The pilot ratings for each configuration are also indicated on these figures along with flying qualities level boundaries from Reference 8.

The open-loop slope $\left(\frac{\Delta A}{\Delta \phi}\right)_\theta$ is high enough for all of the configurations that it is not a factor. The differential phase $\Delta\phi_\theta$ is, however, an important variable in this analysis. As the phase grows more negative, the

pilot ratings become worse. The large negative phase angles correspond to the configurations with extra lags and delays inserted (T_1 = B and C). They also correspond to the configurations with lower levels of augmentation. This indicated that these configurations will require large amounts of pilot lead in the closed loop to achieve desired performance.

TABLE V-D-1

OPEN-LOOP θ/F_{ES} PLUS UNCOMPENSATED PILOT

SLOPE $\left(\frac{\Delta A}{\Delta \phi}\right)_\theta$ VS. DIFFERENTIAL PHASE ($\Delta\phi\theta$)

AT REFERENCE FREQUENCY, ω_θ = 1.2 RAD/SEC

$$\frac{\theta}{\theta_\epsilon}(s) = K_{p_\theta} \frac{5s+1}{s} e^{-.25s} \frac{\theta}{F_{ES}}(s)$$

25 r/s FEEL SYSTEM

CONFIGURATION		LEVEL OF DELAY (T_1)					
		A		B		C	
		$\frac{\Delta A}{\Delta \phi}$, dB/deg	$\Delta\phi\theta$, deg	$\frac{\Delta A}{\Delta \phi}$, dB/deg	$\Delta\phi\theta$, deg	$\frac{\Delta A}{\Delta \phi}$, dB/deg	$\Delta\phi\theta$, deg
<u>Long Aft Tail</u>	Unaug. α	.57	-110			.425	-122
	Low α gain	.41	-103	.36	-111	.325	-116
	Med α	.38	-100	.325	-107	.29	-112
	High α	.25	-93	.225	-101	.21	-106
	Ex-High α	.15	-81				
	High α, N_z/α = 3	.20	-91				
	High α, N_z/α = 2	.15	-89				
	Low q gain	.46	-136			.38	-148
	Med q	.30	-118	.28	-126	.26	-131
	High q	.25	-88	.23	-95	.21	-100
<u>Canard</u>	Unaug	.60	-107				
	Low α	.43	-103	.36	-110	.34	-115
	Med α	.36	-100	.33	-108	.29	-113

TABLE V-D-1 (CONT'D)

OPEN-LOOP θ/F_{ES} PLUS UNCOMPENSATED PILOT

SLOPE $\left(\frac{\Delta A}{\Delta \phi}\right)_\theta$ VS. DIFFERENTIAL PHASE ($\Delta\phi\theta$)

AT REFERENCE FREQUENCY, ω_θ = 1.2 RAD/SEC

$$\frac{\theta}{\theta_\epsilon}(s) = K_{P_\theta} \frac{5s+1}{s} e^{-.25s} \frac{\theta}{F_{ES}}(s)$$

25 r/s FEEL SYSTEM

CONFIGURATION	LEVEL OF DELAY (T_1)					
	A		B		C	
	$\frac{\Delta A}{\Delta \phi}$, dB/deg	$\Delta\phi\theta$, deg	$\frac{\Delta A}{\Delta \phi}$, dB/deg	$\Delta\phi\theta$, deg	$\frac{\Delta A}{\Delta \phi}$, dB/deg	$\Delta\phi\theta$, deg
Canard, cont'd						
High α	.25	-95	.24	-103	.21	-108
Ex-High α	.12	-82				
High q	.26	-85				
Short Aft Tail Med α	.38	-100	.33	-107		
High α	.28	-93	.25	-101		
Med q	.31	-127				
High q	.24	-93			(.19	-113)*
Ex-High q	.15	-51				

*T_1 = .35 (shuttle lag/delay)

$$\text{Open-Loop } \frac{\theta}{\theta_\varepsilon}(s) = K_{p_\theta} \frac{5s+1}{s} e^{-.25s} \frac{\theta}{F_{ES}}(s)$$

Slope & Δ Phase at ω_θ = 1.2 rad/sec

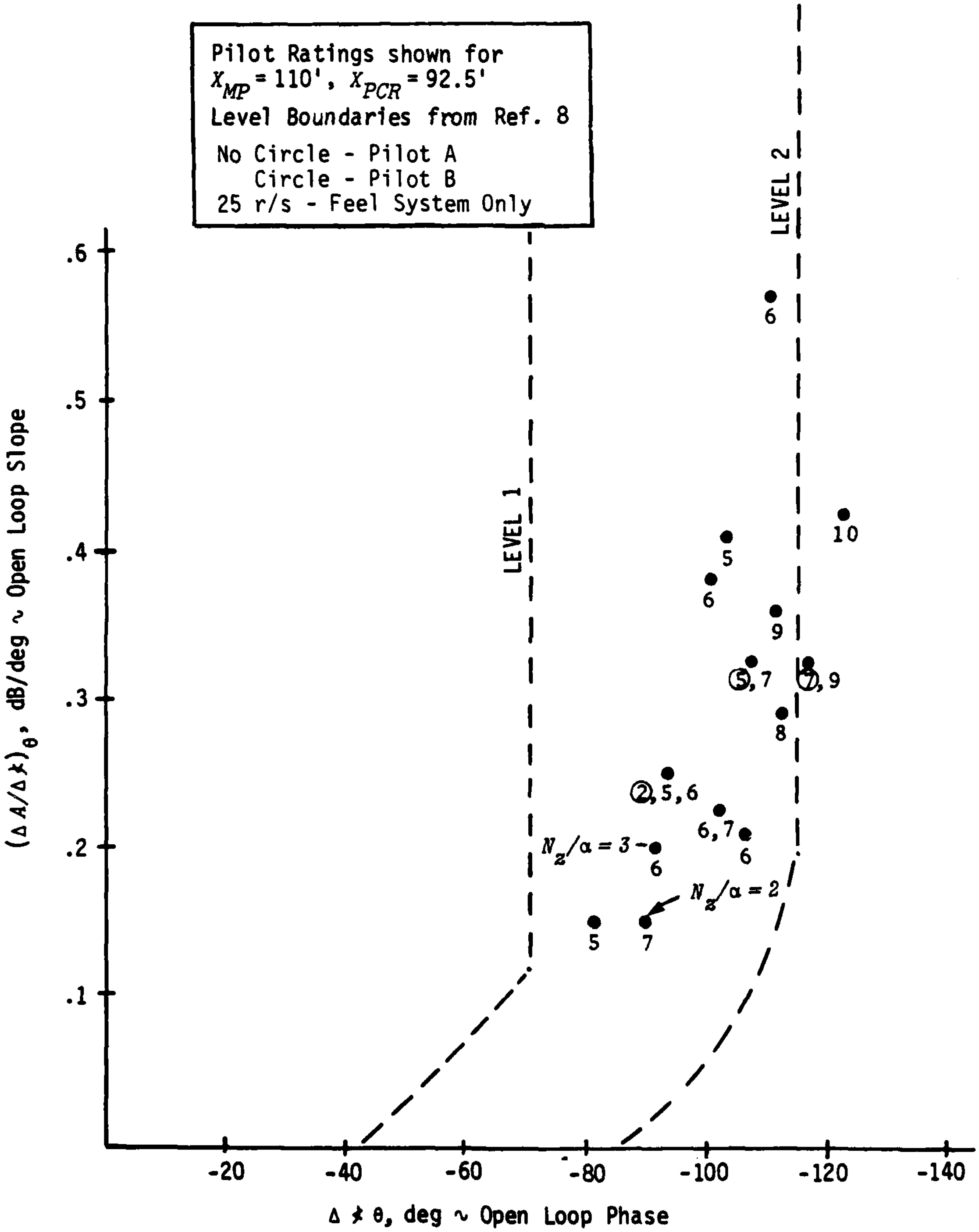


Figure V-D-1. LONG AFT TAIL α- FEEDBACK OPEN LOOP θ/F_{ES} PLUS UNCOMPENSATED PILOT, SLOPE VS PHASE

$$\text{Open Loop } \frac{\theta}{\theta_\varepsilon}(s) = K_{p_\theta} \frac{5s+1}{s} e^{-.25s} \frac{\theta}{F_{ES}}(s)$$

Slope & Δ Phase at ω_θ = 1.2 rad/sec

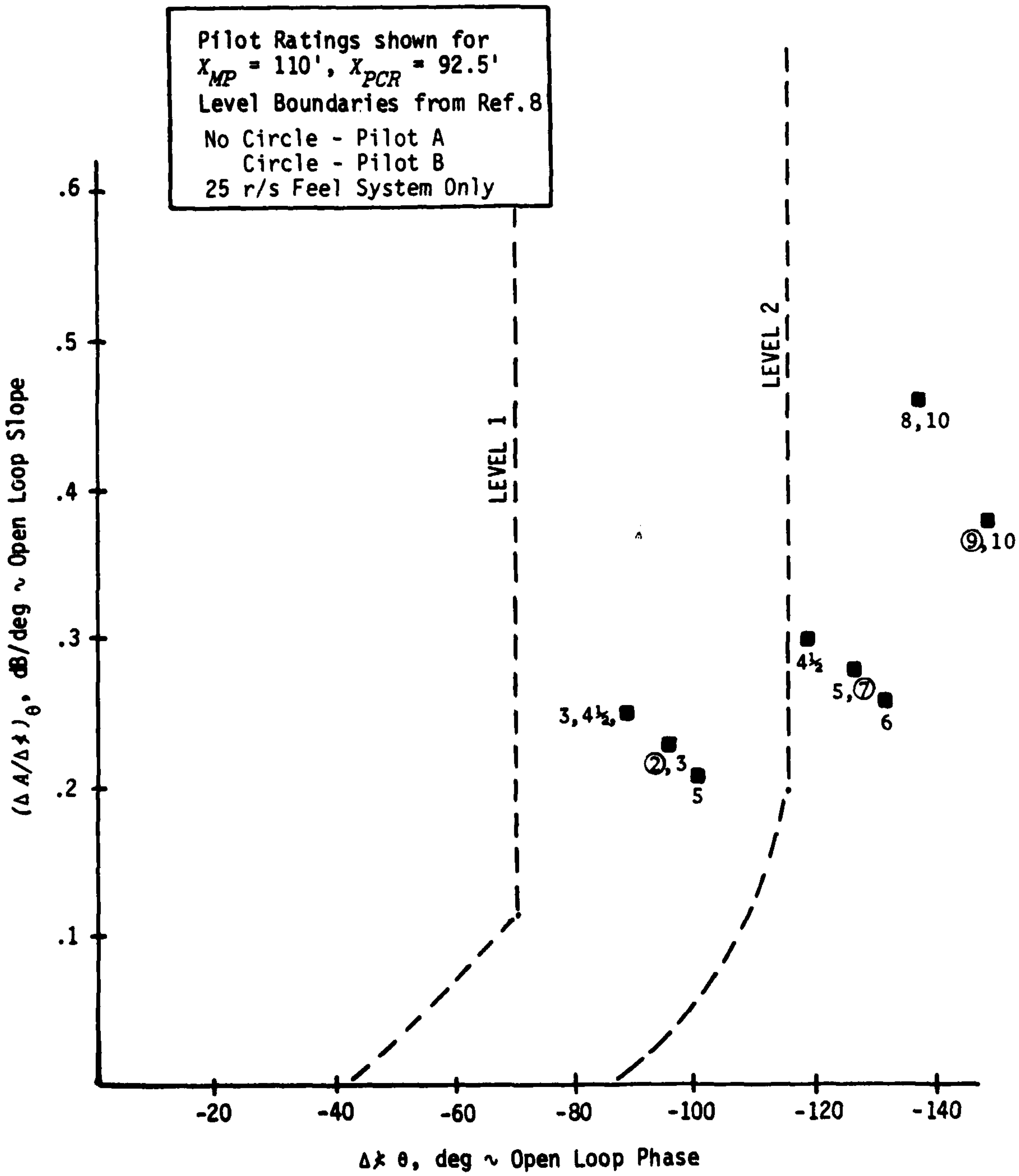


Figure V-D-2. LONG AFT TAIL q- FEEDBACK OPEN LOOP θ/F_{ES} PLUS UNCOMPENSATED PILOT, SLOPE VS PHASE

$$\text{Open Loop } \frac{\theta}{\theta_\varepsilon}(s) = K_{p_\theta} \frac{5s+1}{s} e^{-.25s} \frac{\theta}{F_{ES}}(s)$$

Slope & Δ Phase at ω_θ = 1.2 rad/sec

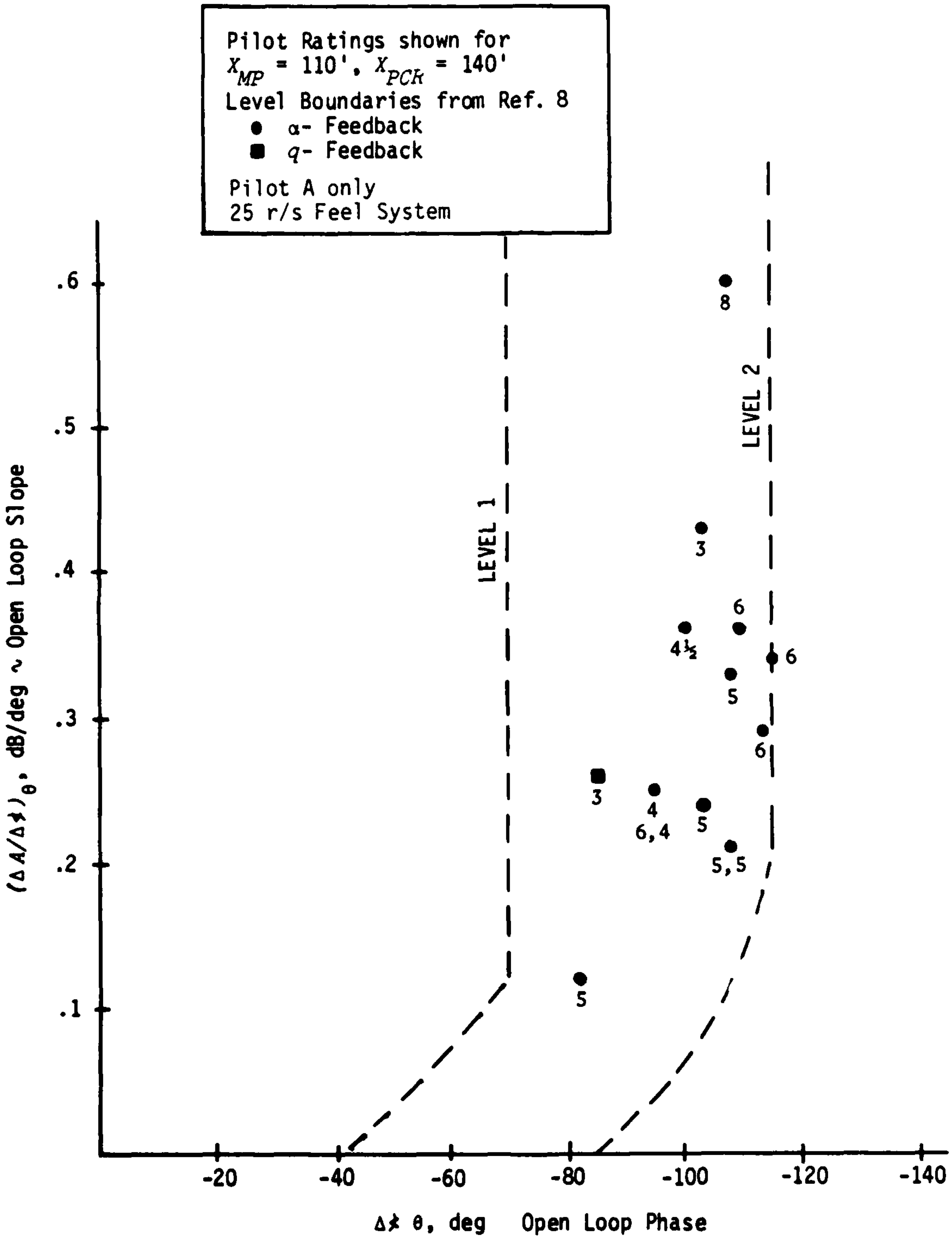


Figure V-D-3. CANARD OPEN LOOP θ/F_{ES} PLUS UNCOMPENSATED PILOT, SLOPE VS PHASE

$$\text{Open-Loop } \frac{\theta}{\theta_\varepsilon}(s) = K_{p_\theta} \frac{5s+1}{s} e^{-.25s} \frac{\theta}{F_{ES}}(s)$$

Slope & Δ Phase at ω_θ = 1.2 rad/sec

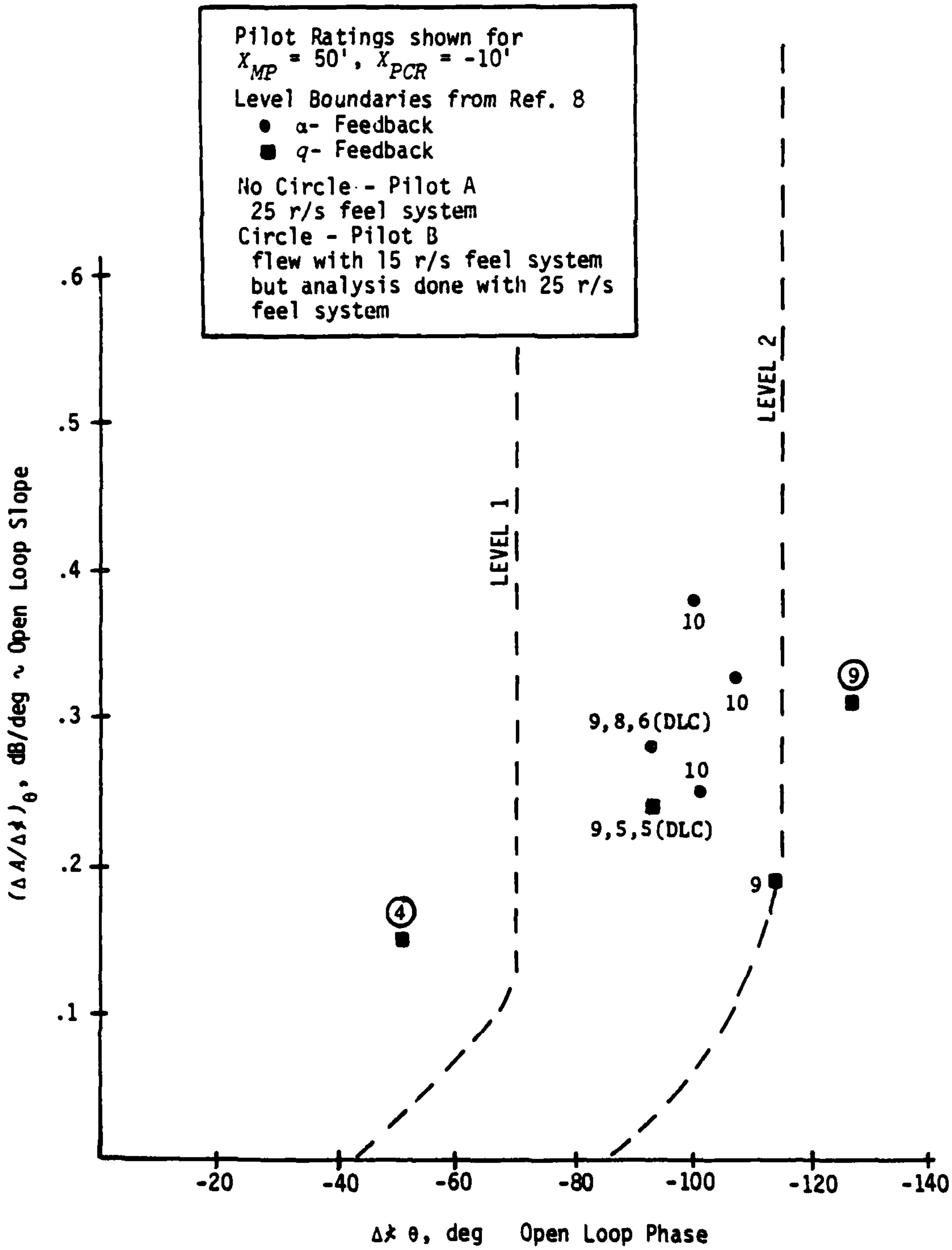


Figure V-D-4. SHORT AFT TAIL OPEN LOOP θ/F_{ES} PLUS UNCOMPENSATED PILOT, SLOPE VS PHASE

OPEN-LOOP AIRCRAFT PLUS UNCOMPENSATED PILOT NICHOLS DIAGRAMS, $\theta/\theta_\varepsilon$

The following figures present the open-loop aircraft plus uncompensated pilot Nichols diagrams for each configuration evaluated. The pilot model contains a .25 second delay and low frequency integration capability $\left(\frac{5s+1}{s}\right)$. The gain ($K_{P_\theta}$) was adjusted to normalize the curves to force them through 0 dB at ω = 1. rad/sec.

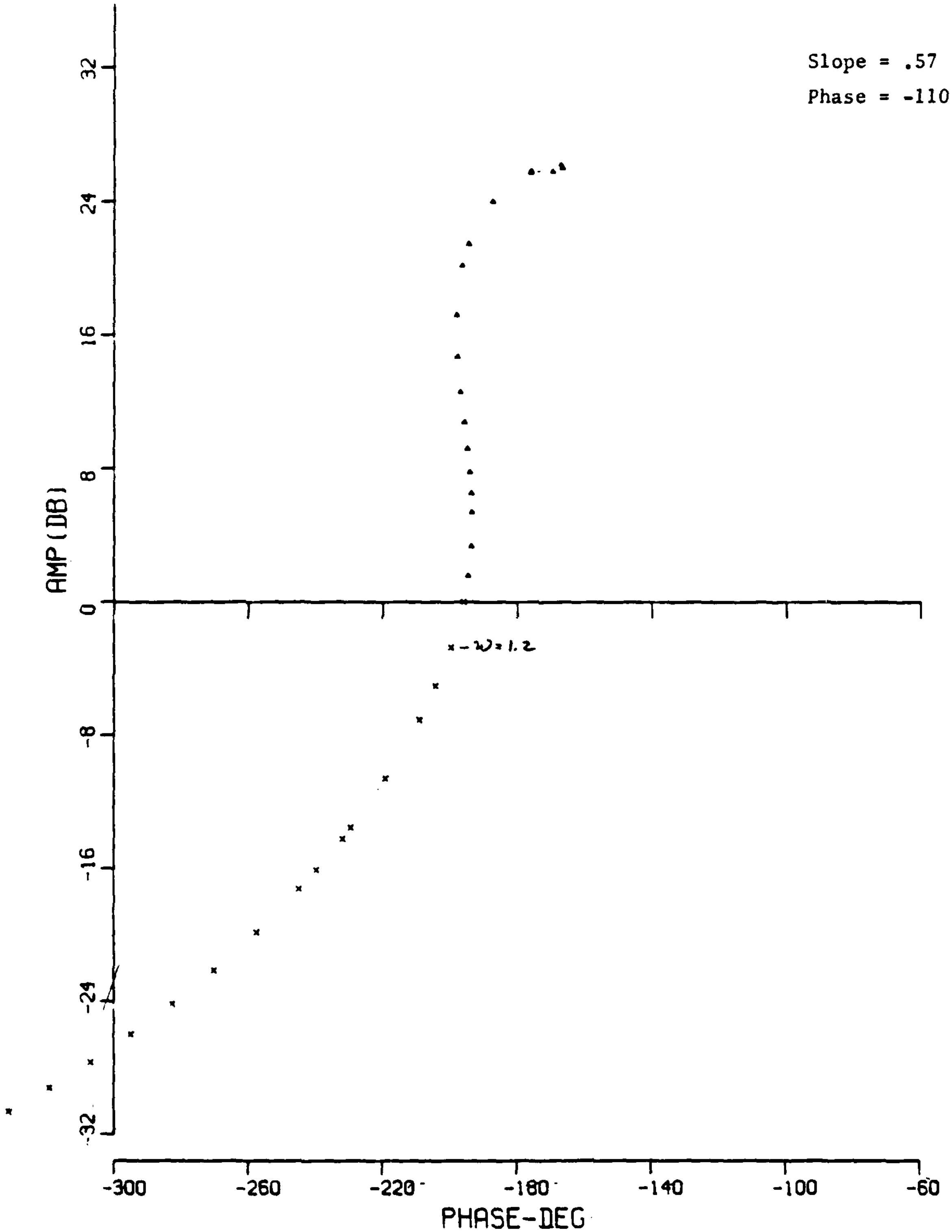
$$\theta/\theta_\varepsilon = K_{P_\theta} e^{-.25s} \left(\frac{5s+1}{s}\right) \theta/F_{ES}$$

(25 r/s feel system was used).

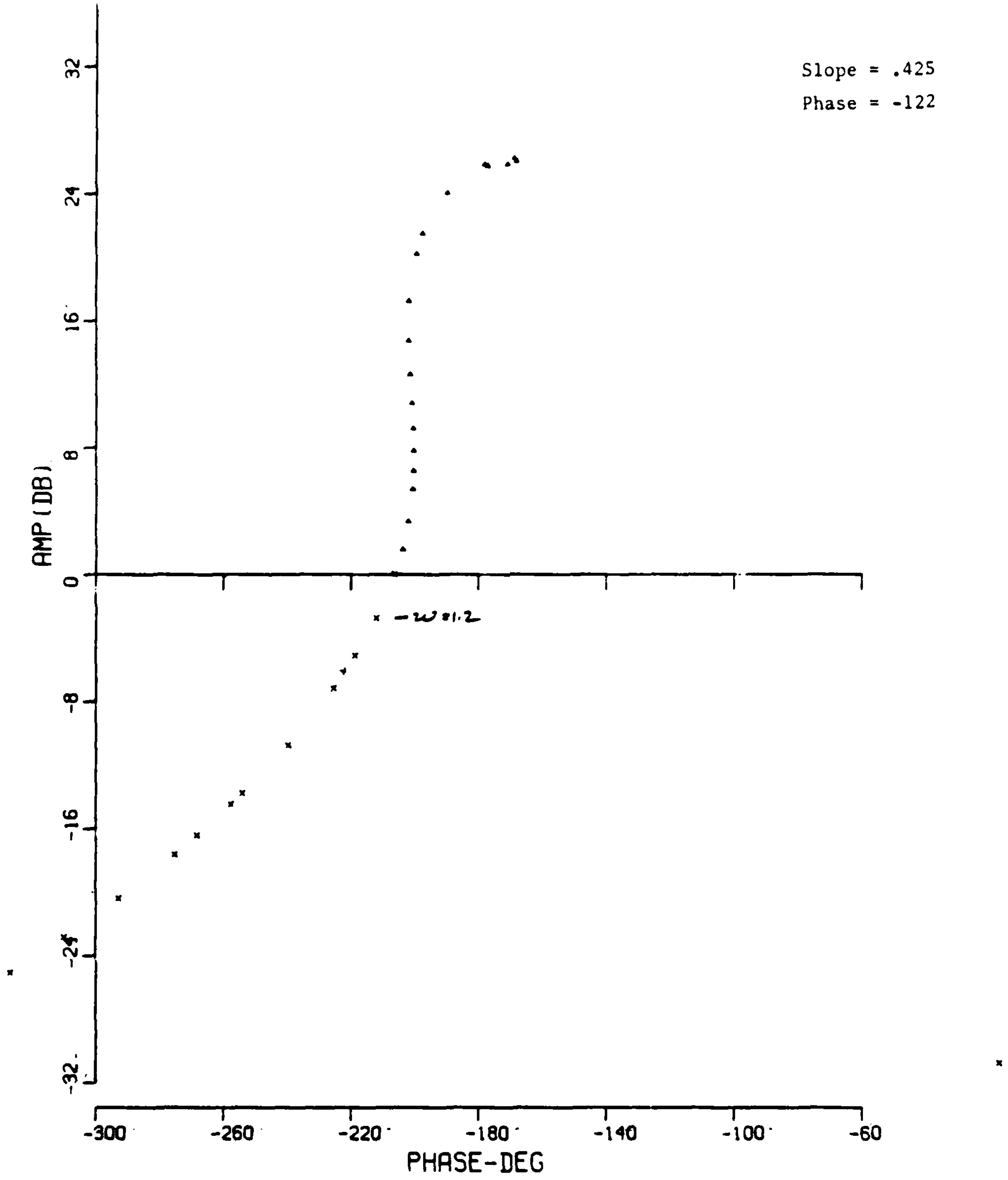
The measurements taken from these plots were the slope $\left(\frac{\Delta A}{\Delta \measuredangle}\right)_\theta$, dB/deg and the differential phase at 1.2 rad/sec ($\Delta\measuredangle_\theta$ = [phase @ ω = 1.2 rad] + 90 deg). The captions on each plot define the configuration. The order of the frequency points is:

ω *(rad/sec)* ▲ = .1, .12, .14, .16, .2, .24, .28, .3, .35, .4, .45, .6, .65, .7, .8, .9

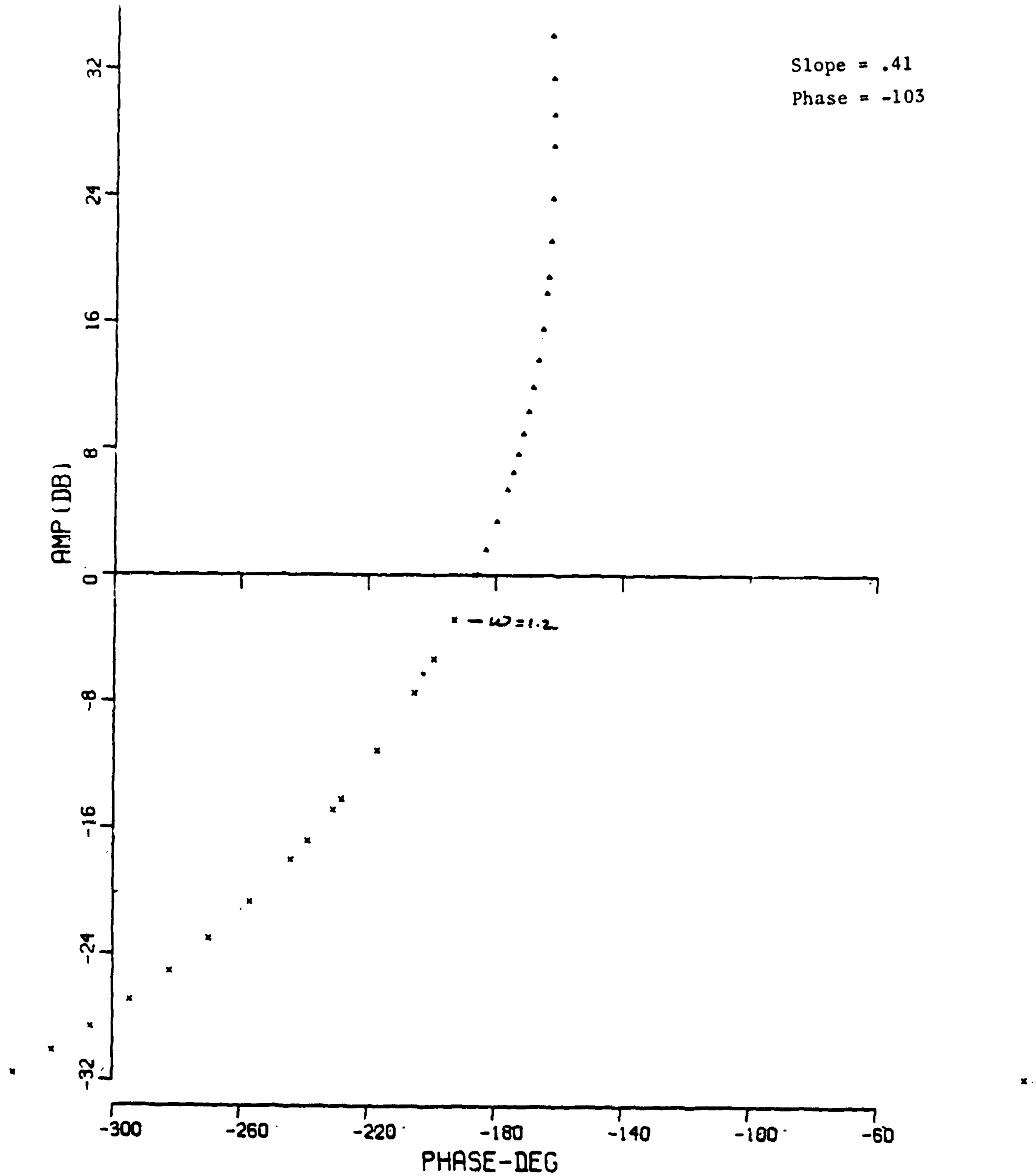
X = above frequencies x 10.



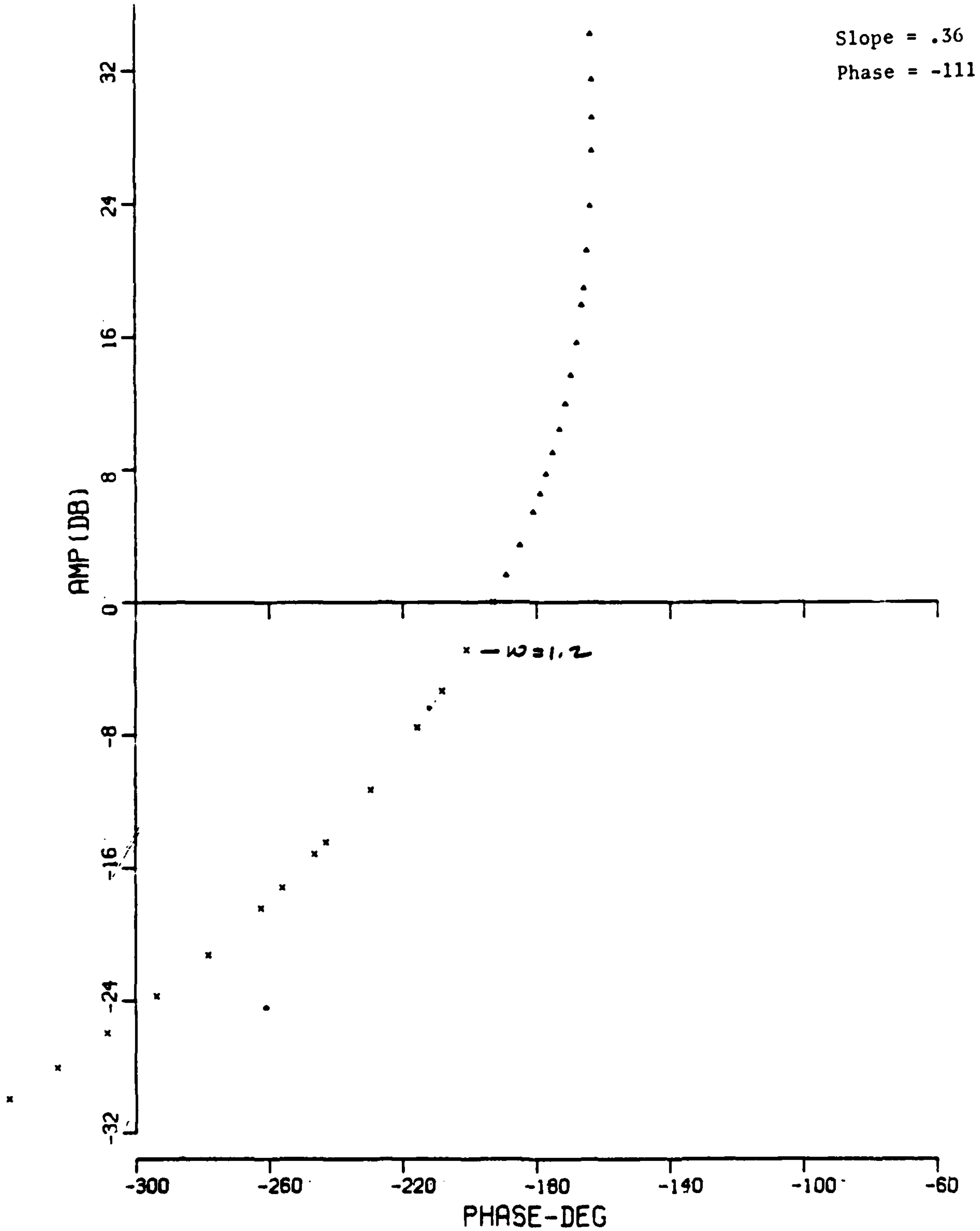
22 APR 1981 L.F. INT - LONG AFT - ALPHA FDBK - KA=0.00 - UNAUG - DELAY=A



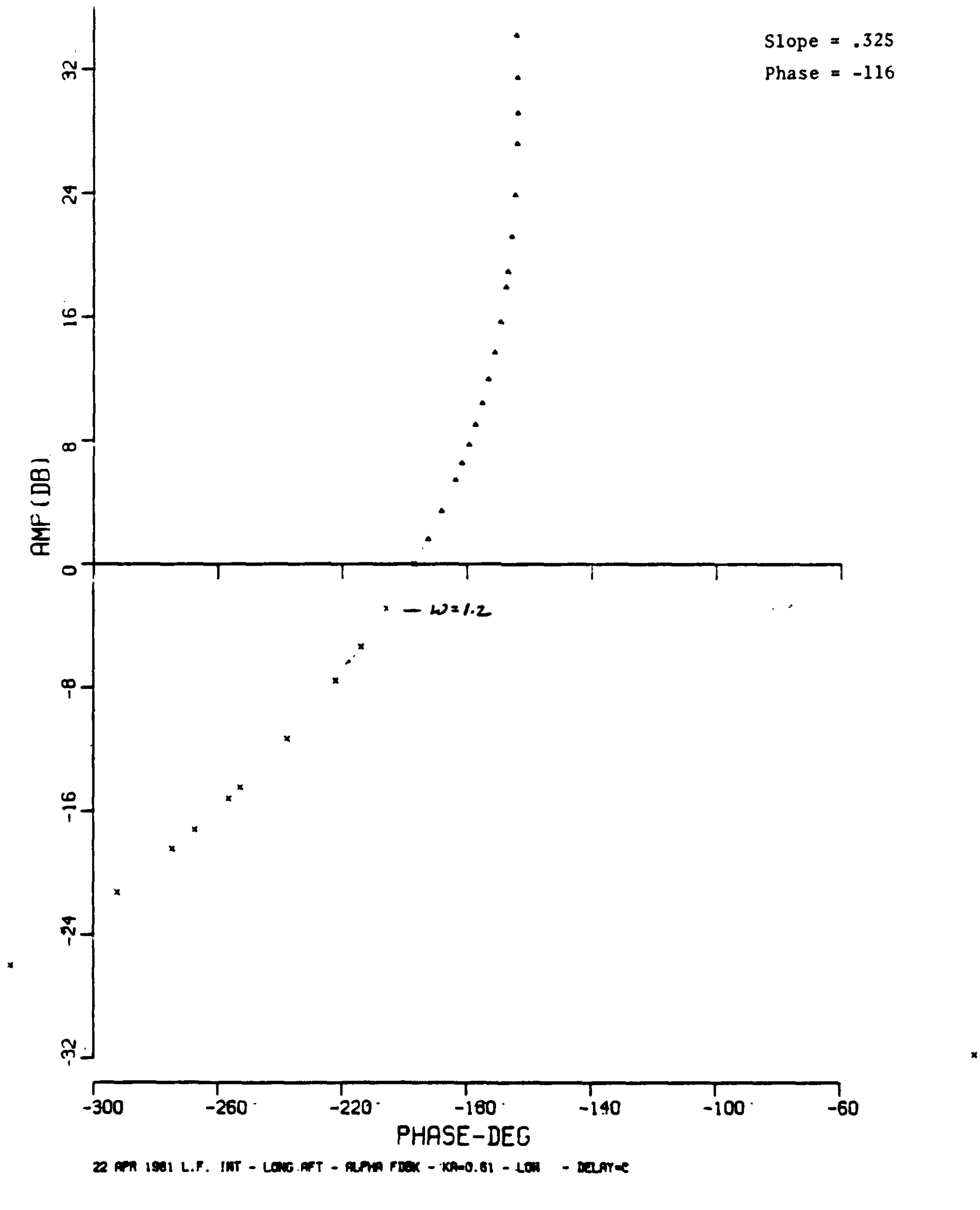
22 APR 1981 L.F. IRT - LONG AFT - ALPHA FDBK - KA=0.00 - UNAUG - DELAY=C



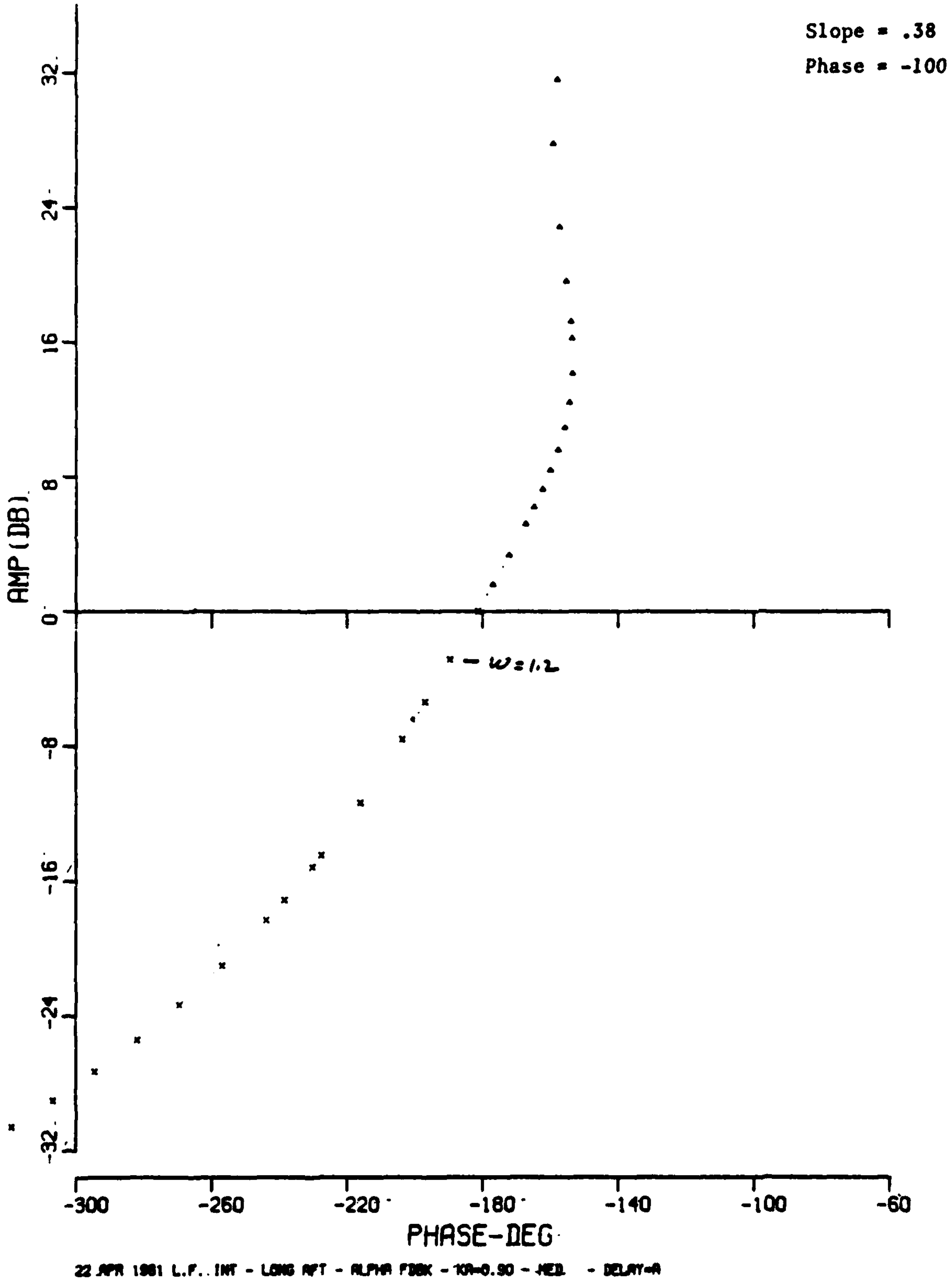
22 APR 1981 L.F. IRT - LONG AFT - ALPHA FDBK - KA=0.61 - LOW - DELAY=A



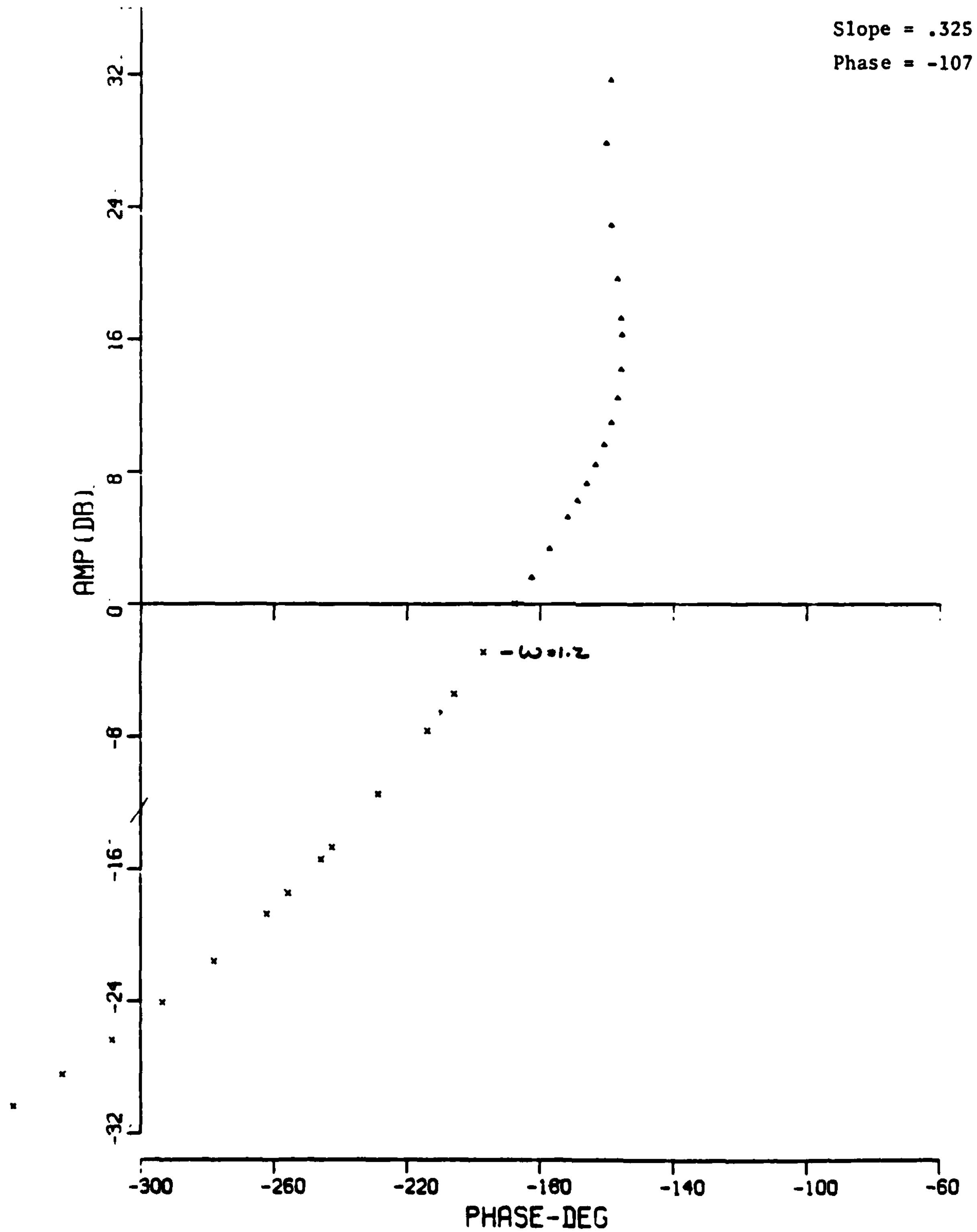
22 APR 1981 L.F. INT - LONG AFT - ALPHA FDBK - KA=0.61 - LOW - DELAY=8



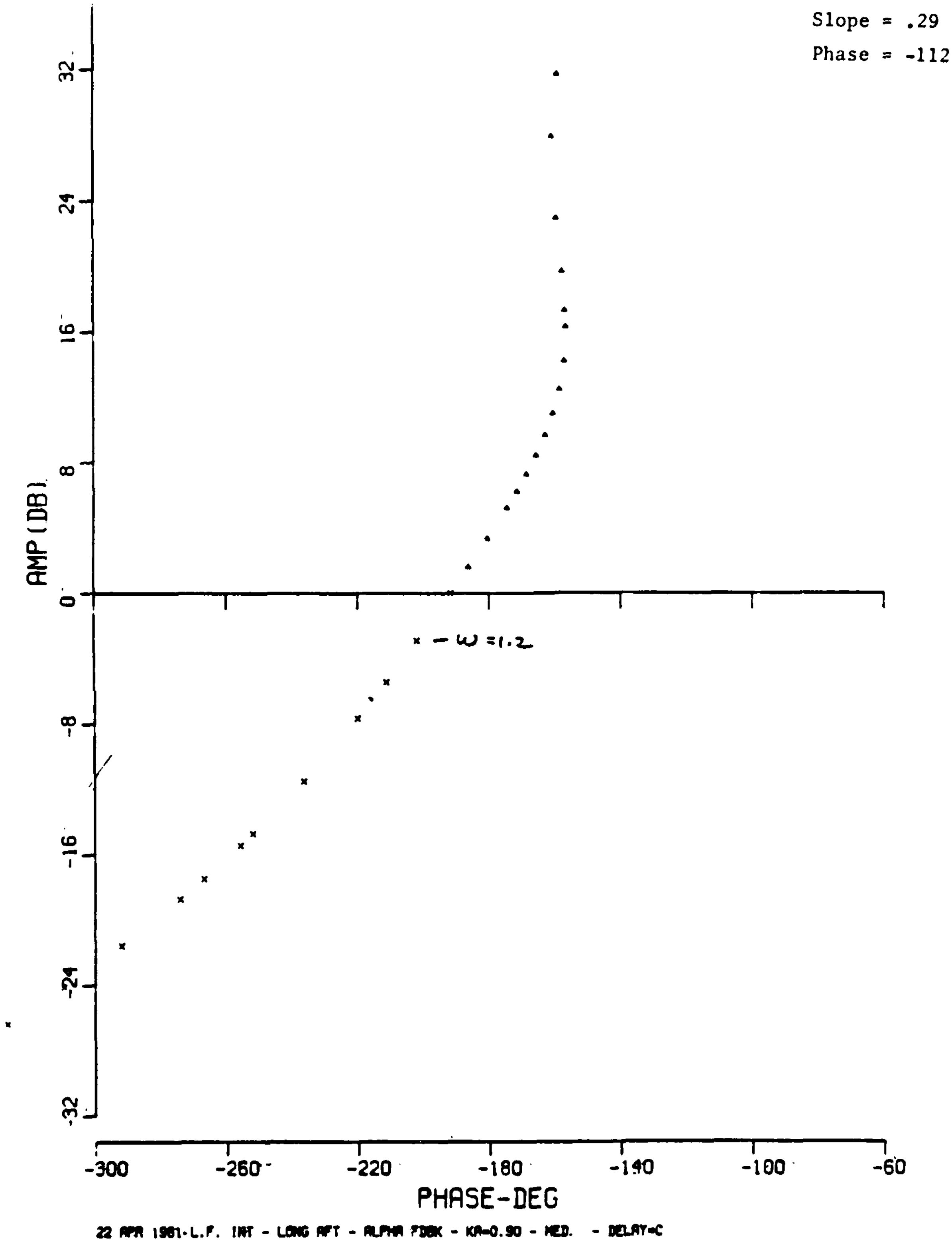
Slope = .325
Phase = -116
× — ω=1.2
AMP (DB)
PHASE-DEG
22 APR 1981 L.F. INT - LONG AFT - ALPHA FDBK - KA=0.61 - LOW - DELAY=C

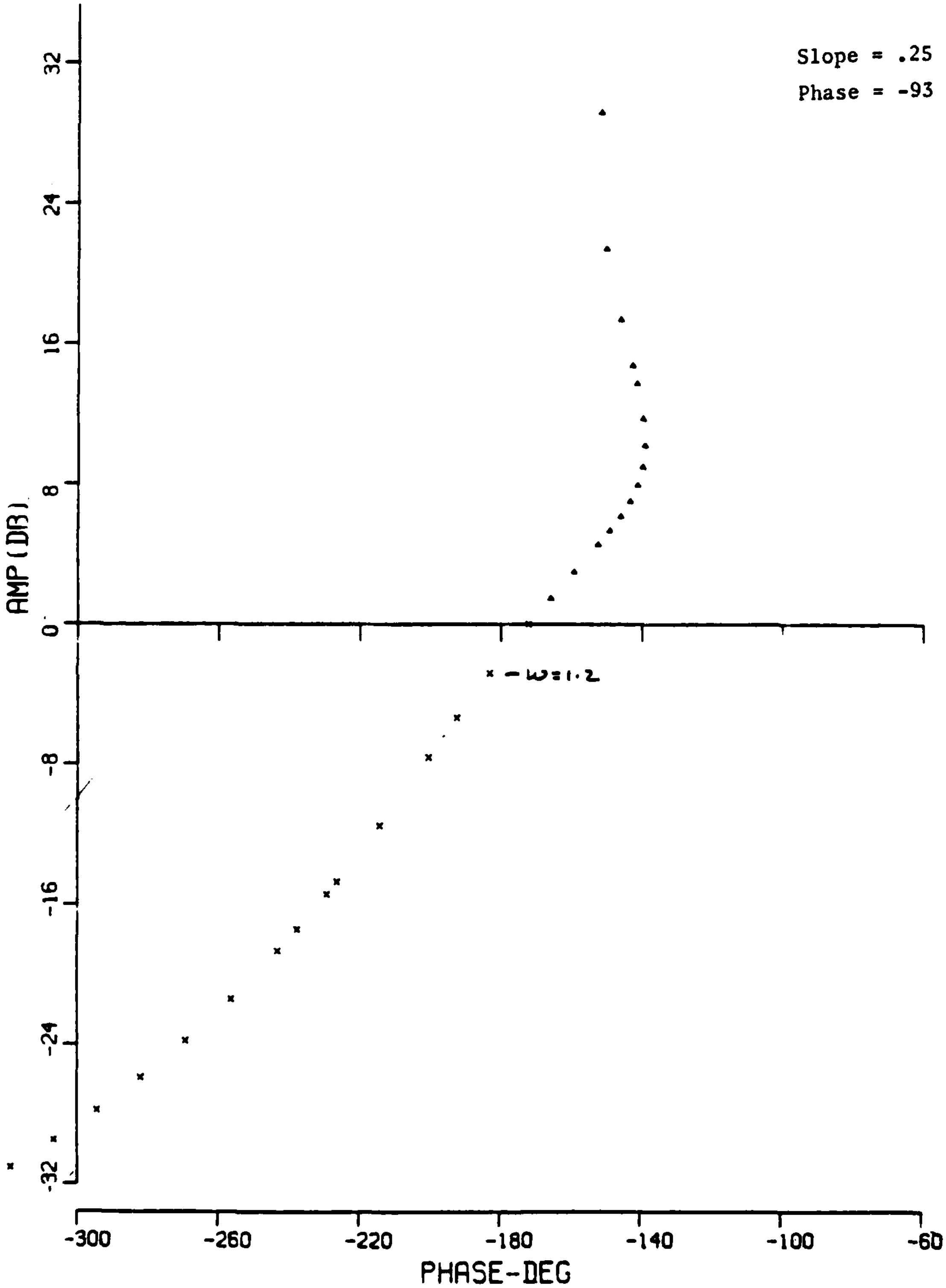


Slope = .38
Phase = -100
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
x — ω=1.2
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
22 APR 1981 L.F..INT - LONG AFT - ALPHA FDBK - KA=0.90 - MED. - DELAY=A

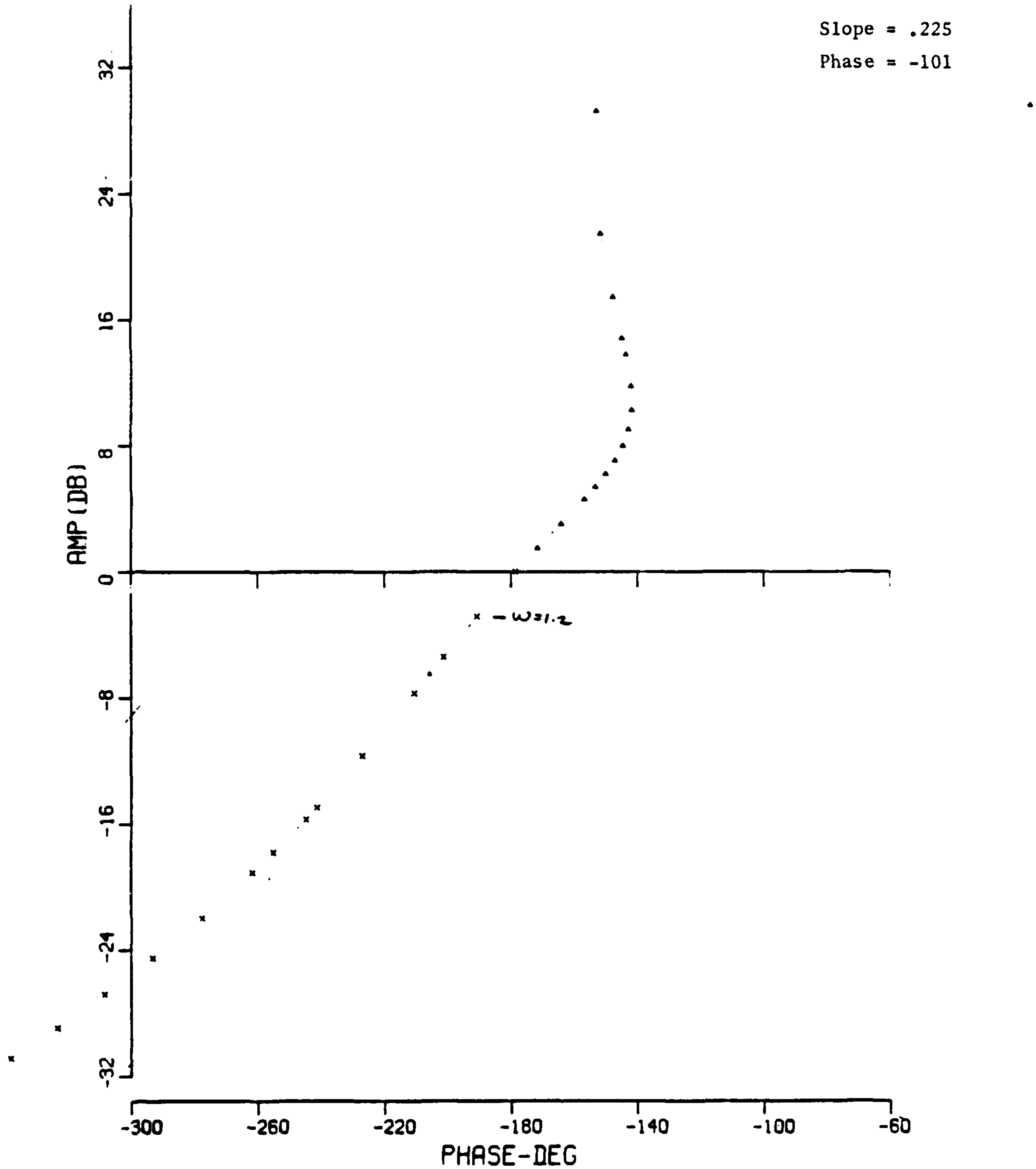


22 APR 1981 L.F. INT - LONG.APT - ALPHA FDBK - KA=0.90 - MED. - DELAY=8

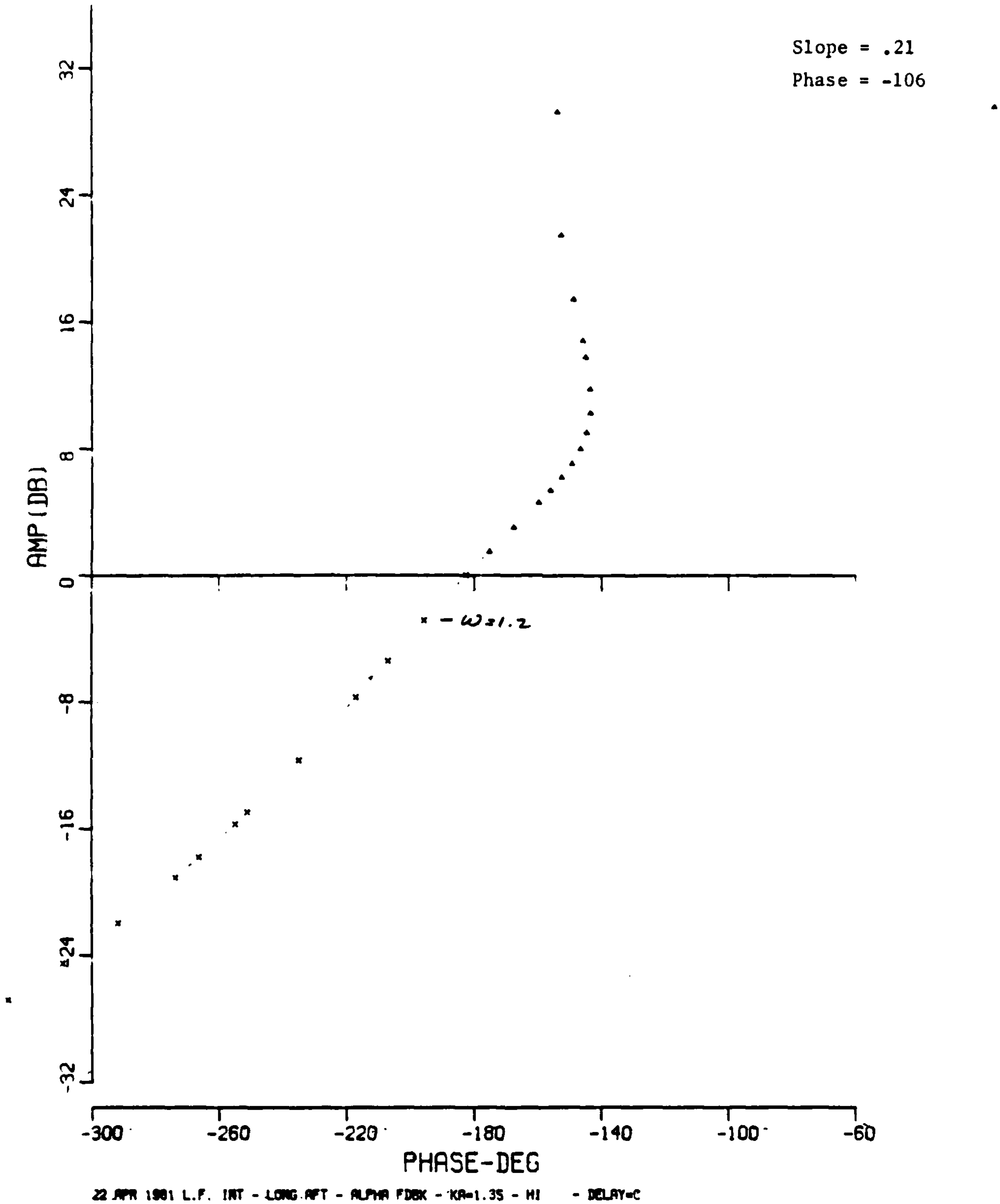

Slope = .29
Phase = -112
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
x — ω = 1.2
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
22 APR 1981-L.F. INT - LONG AFT - ALPHA FDBK - KA=0.90 - MED. - DELAY=C



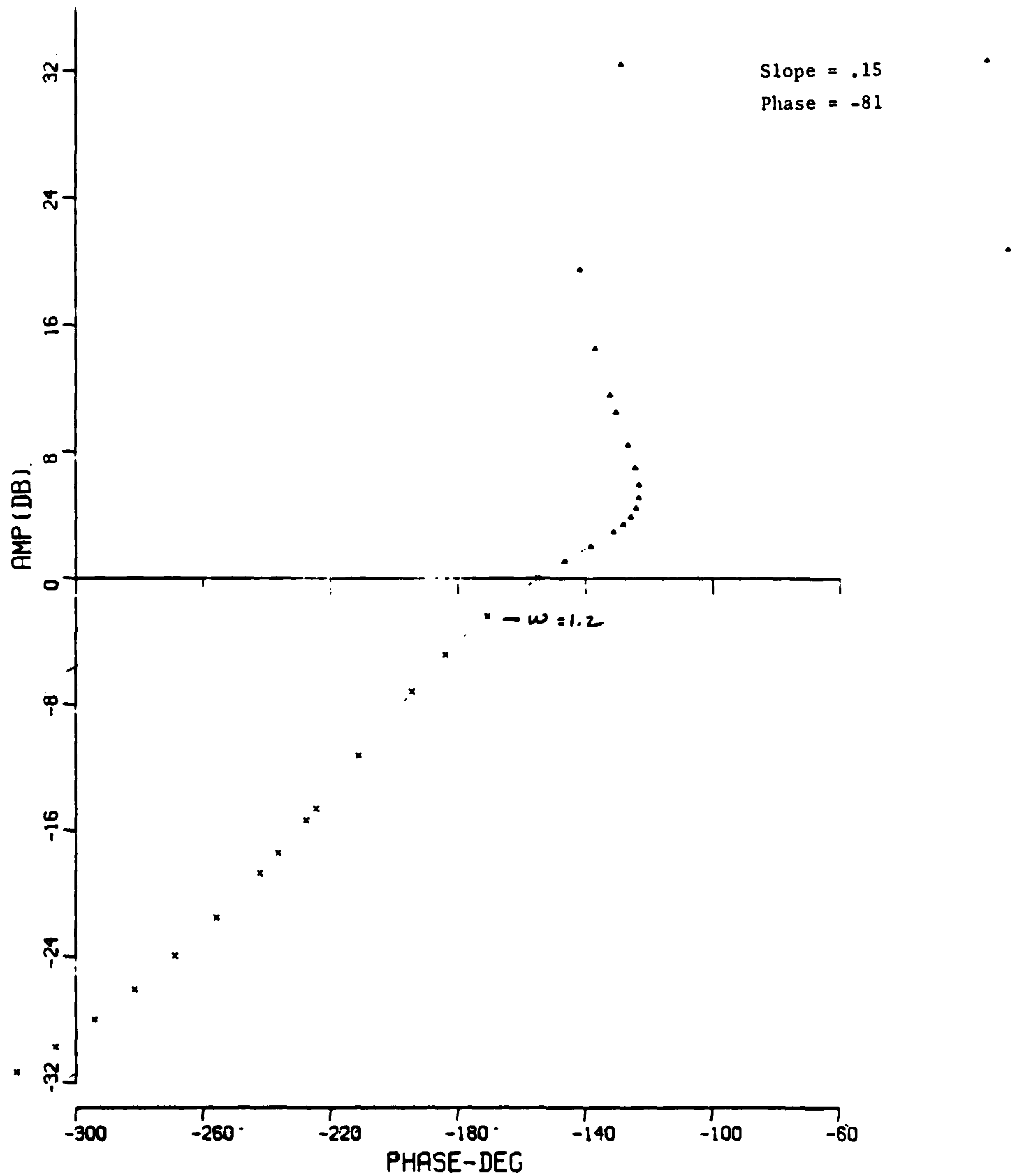
22 APR 1981.L.F. IRT - LONG AFT - ALPHA FDBK - KA=1.35 - HI - DELAY=A



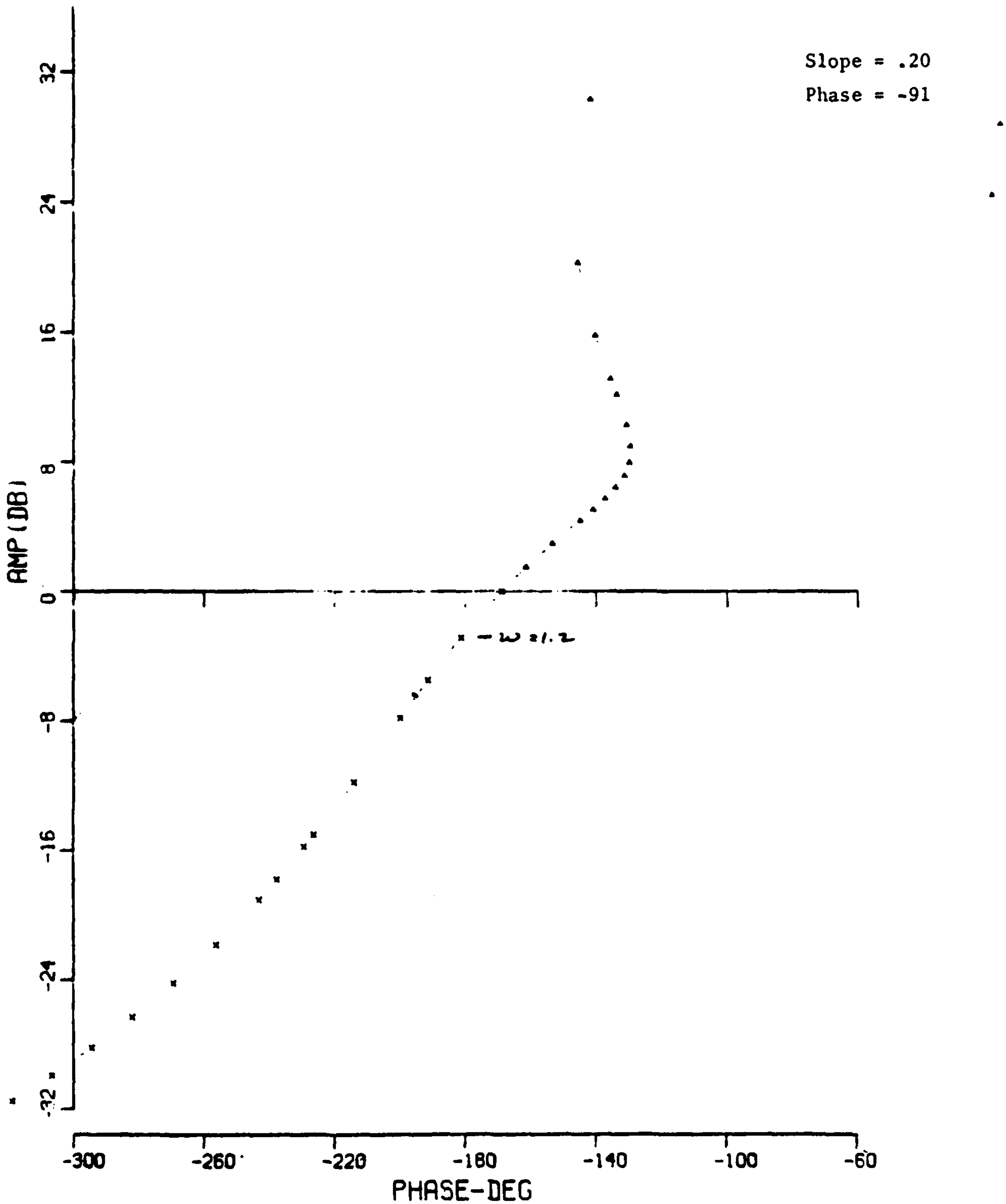
22 APR 1981 L.F. INT - LONG AFT - ALPHA FDBK - KA=1.35 - HI - DELAY=8



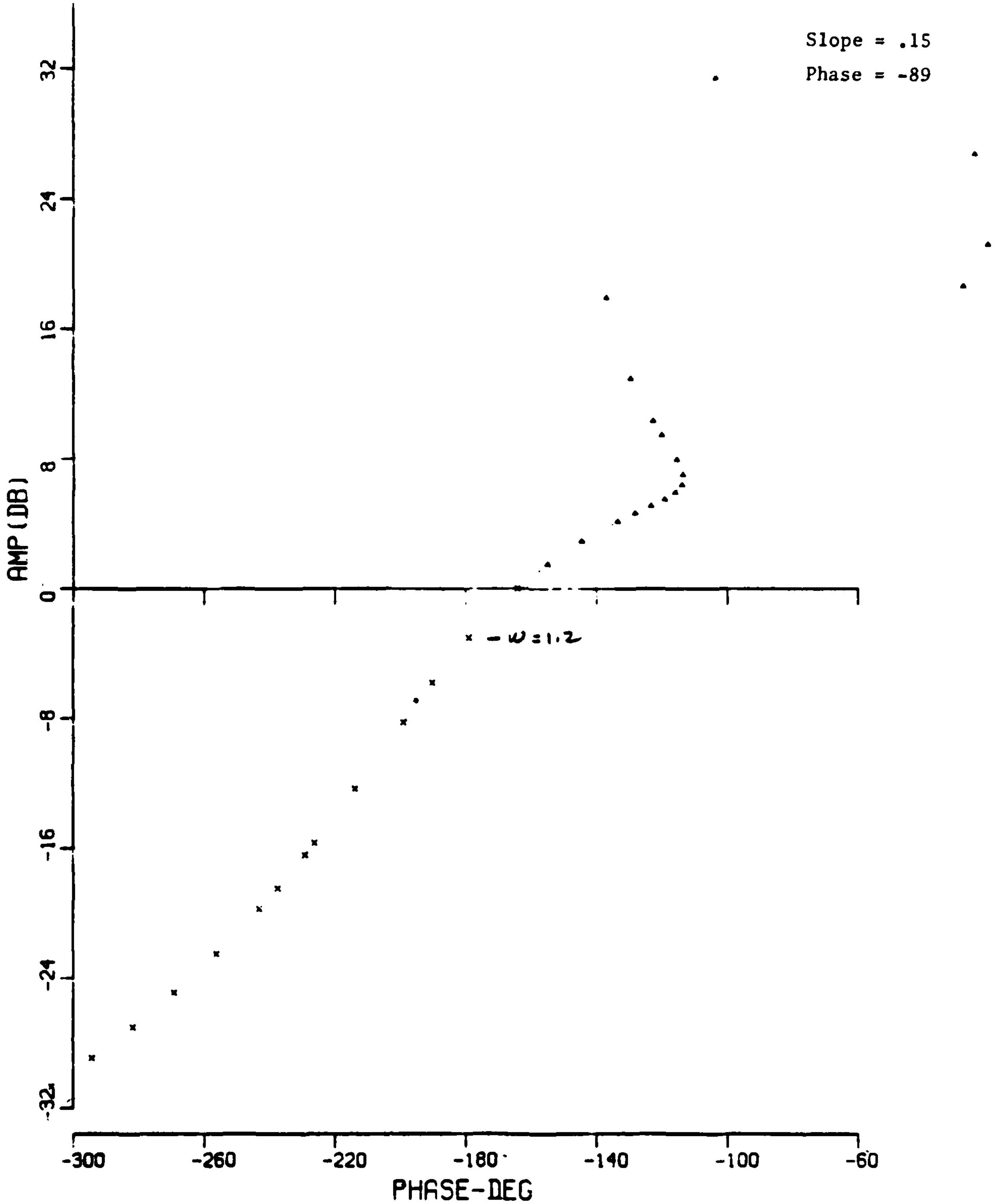
Slope = .21
Phase = -106
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
× – ω=1.2
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
22 APR 1981 L.F. INT - LONG AFT - ALPHA FDBK - KA=1.35 - HI - DELAY=C



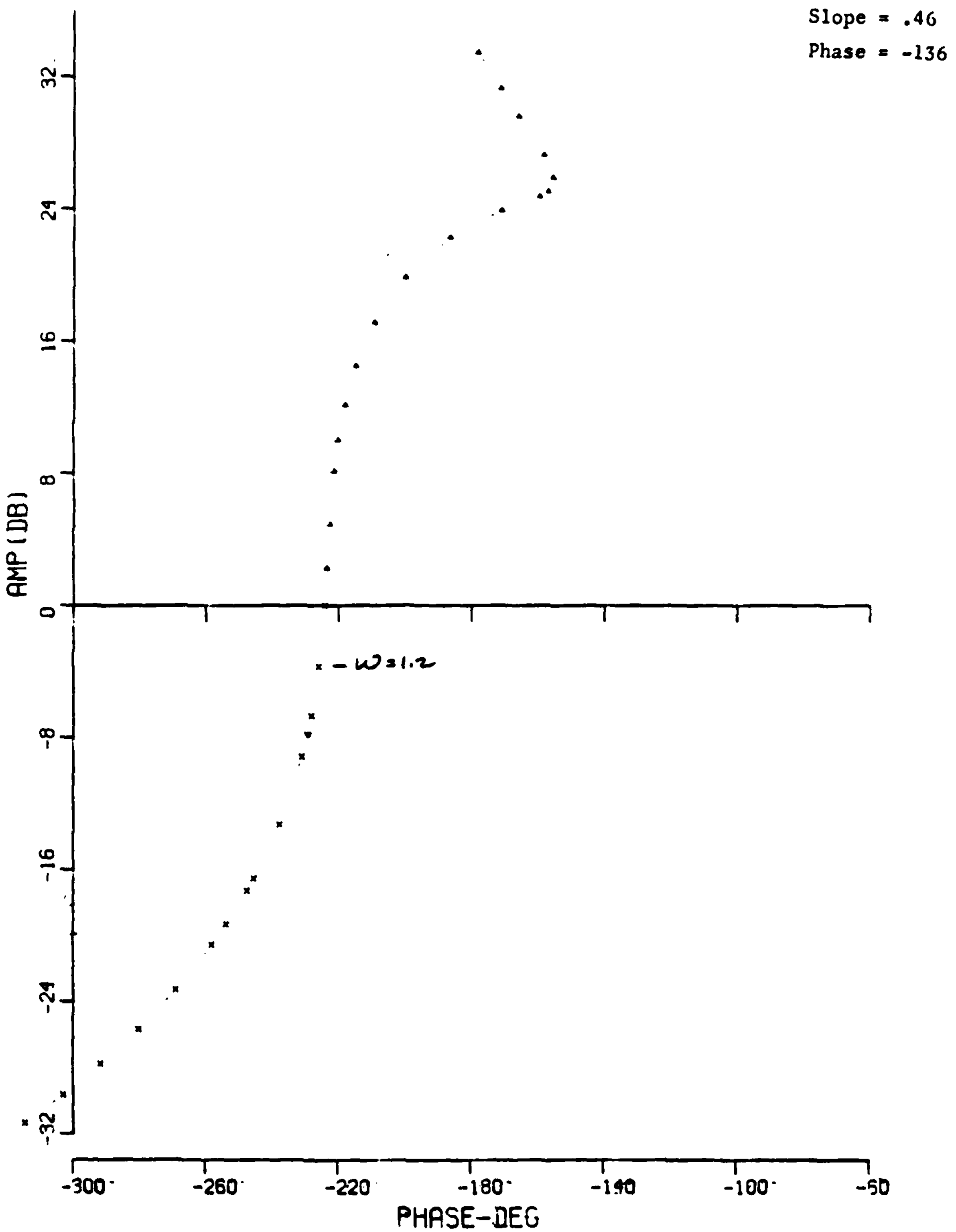
22 APR 1981 L.F. INT - LONG.AFT - ALPHA FDBK - KA=2.10 - EX-HI - DELAY=A



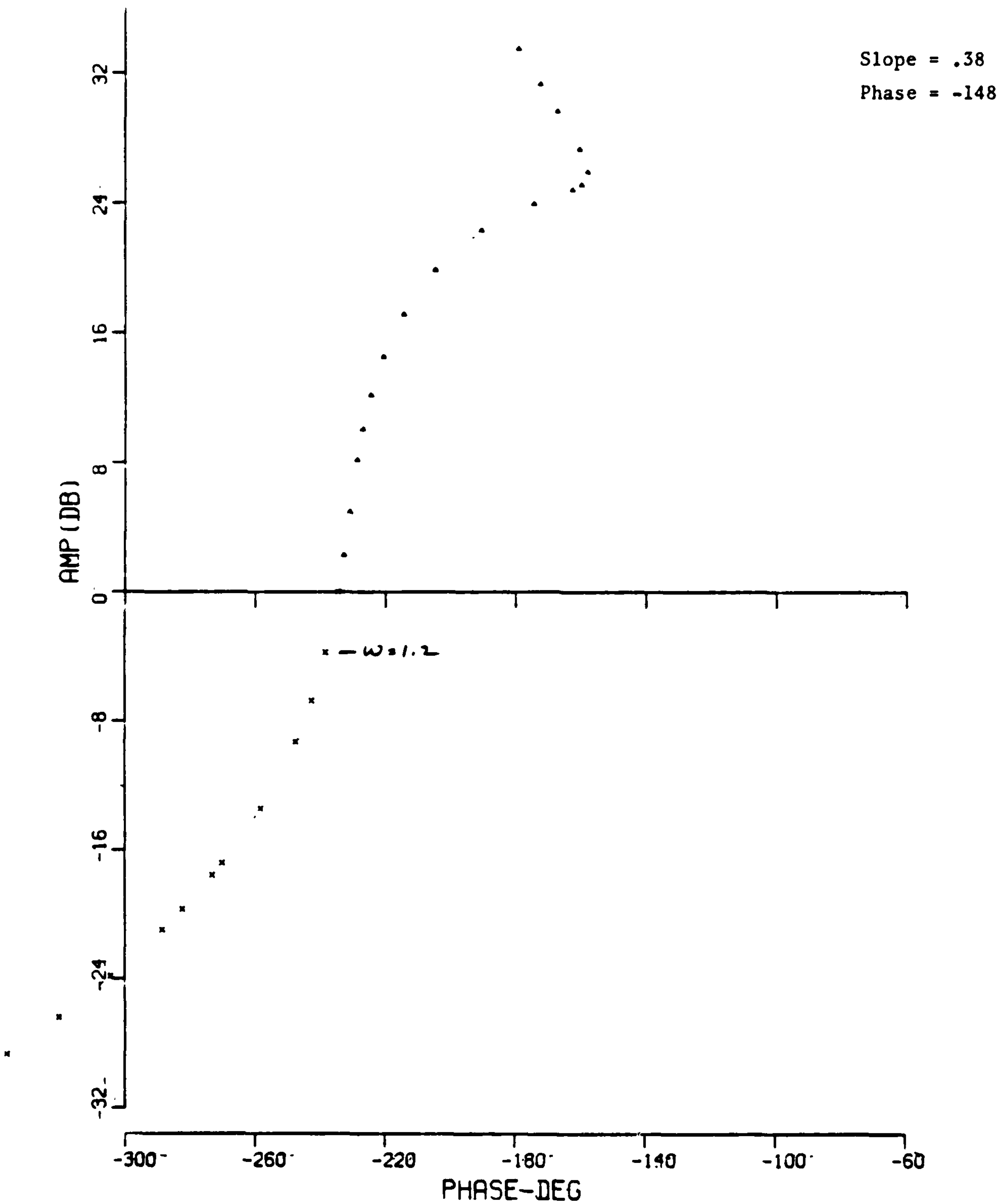
. 22 APR 1981 L.F. INT - LONG AFT - ALPHA FDBK - KA=HI - NZ/A=3. - DELAY=A



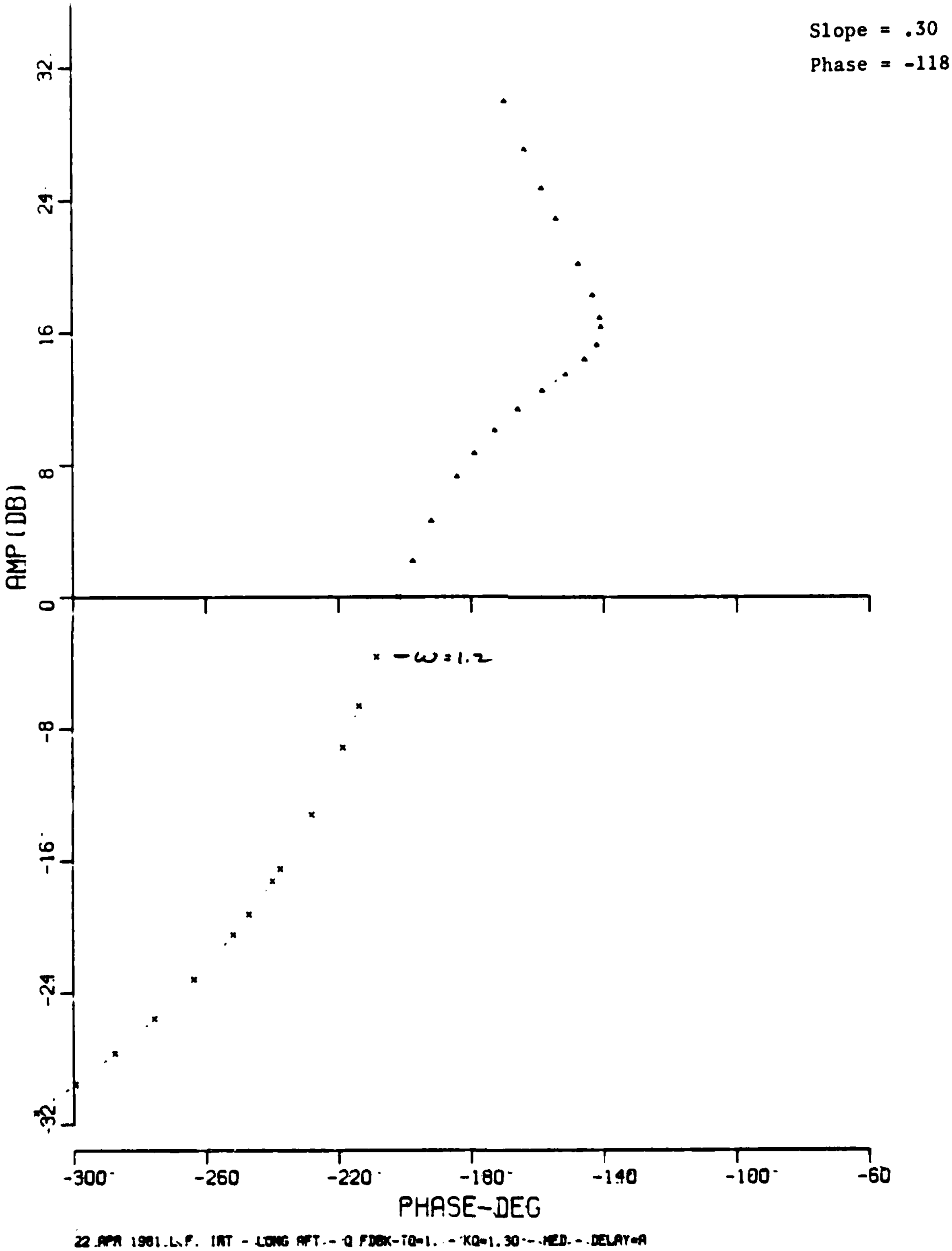
22 APR 1981 L.F. IRT - LONG AFT - ALPHA FDBK - KA=HI - NZ/A=2. - DELAY=A

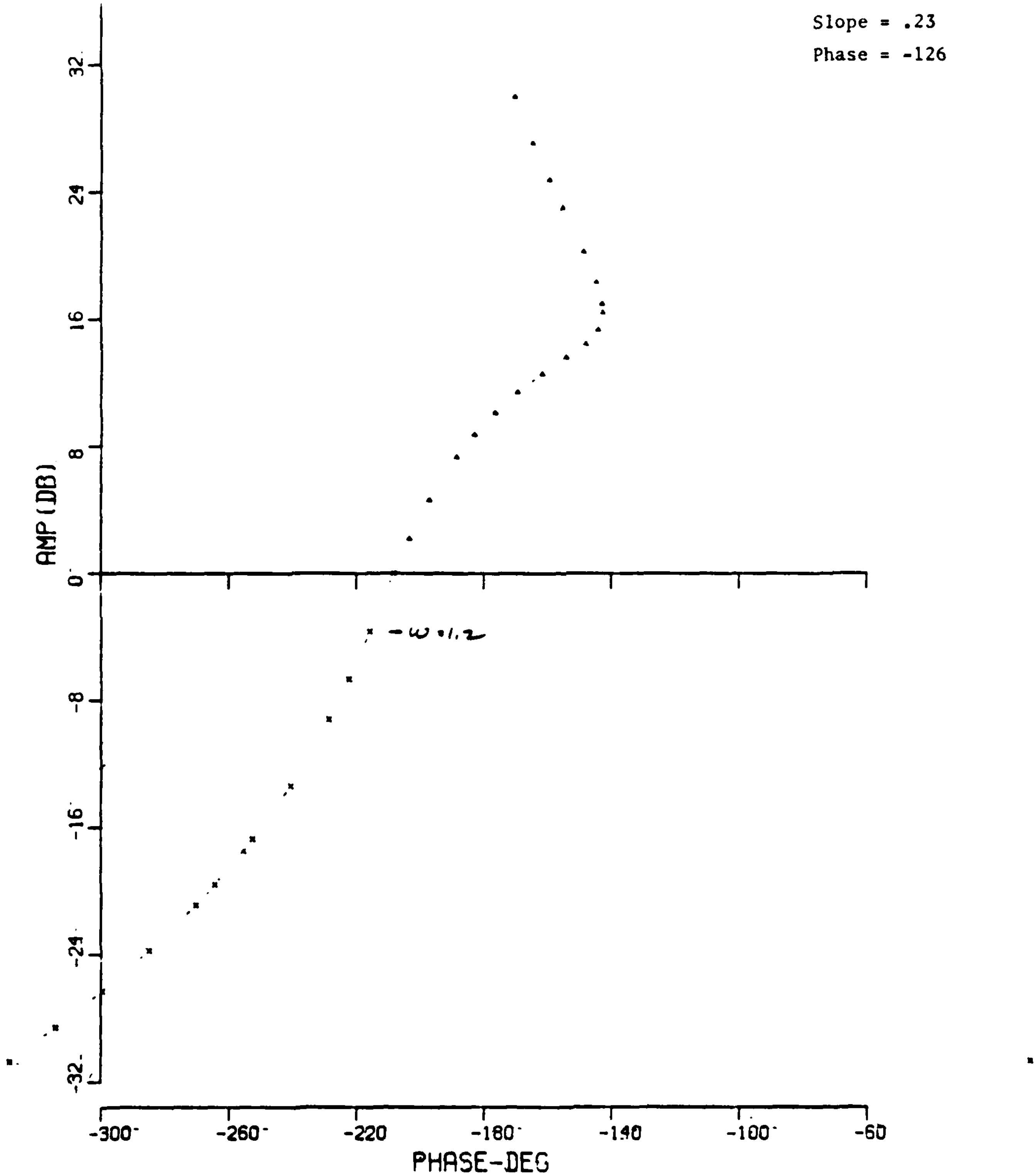


22 APR 1981 L.F. IRT - LONG APT - Q FDBK-TQ=1. - KQ=0.60 - LOR - DELAY=A

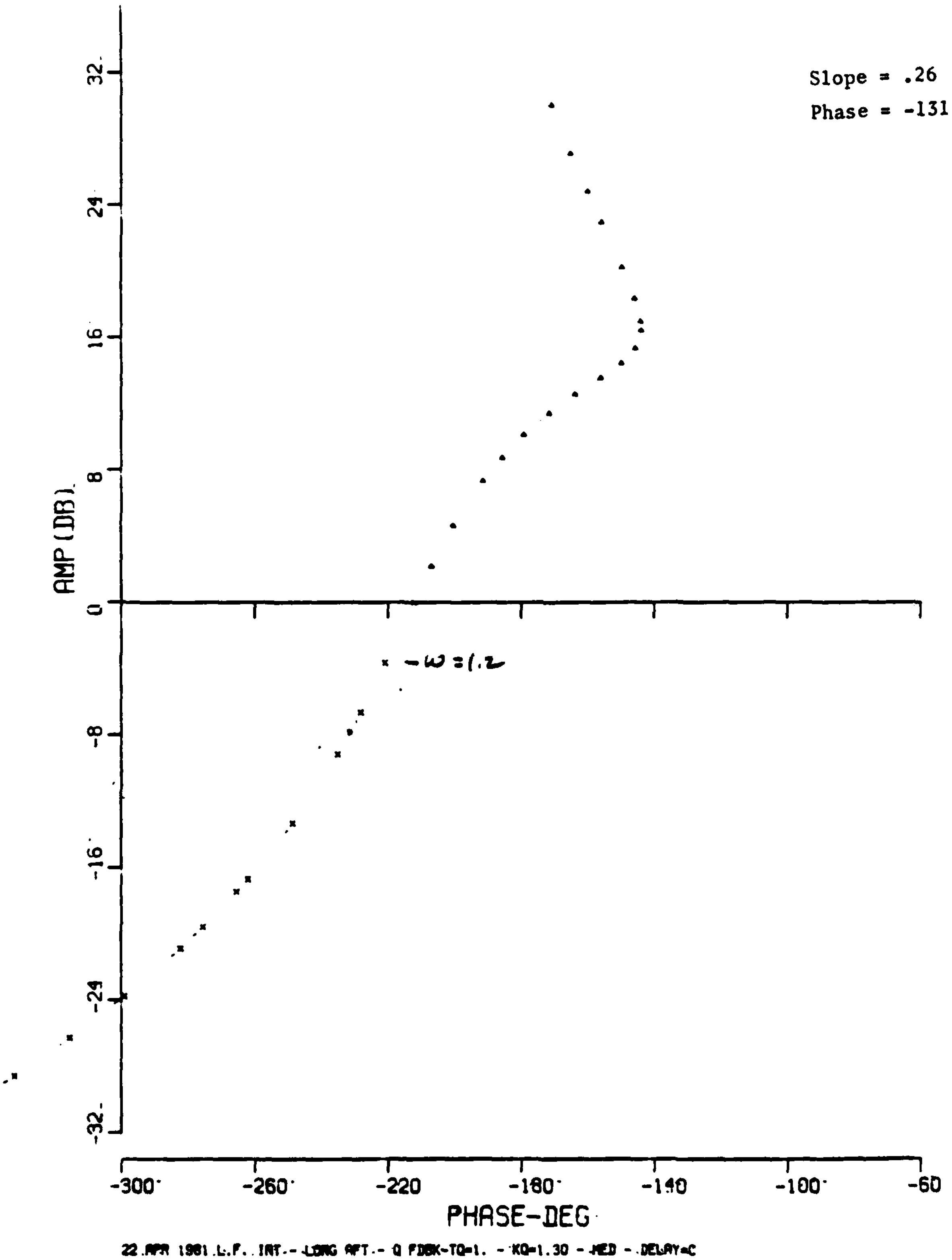


22 APR 1981 L.F. INT - LONG AFT - Q FDBK-TQ=1. - KQ=0.60 - LOW - DELAY=C

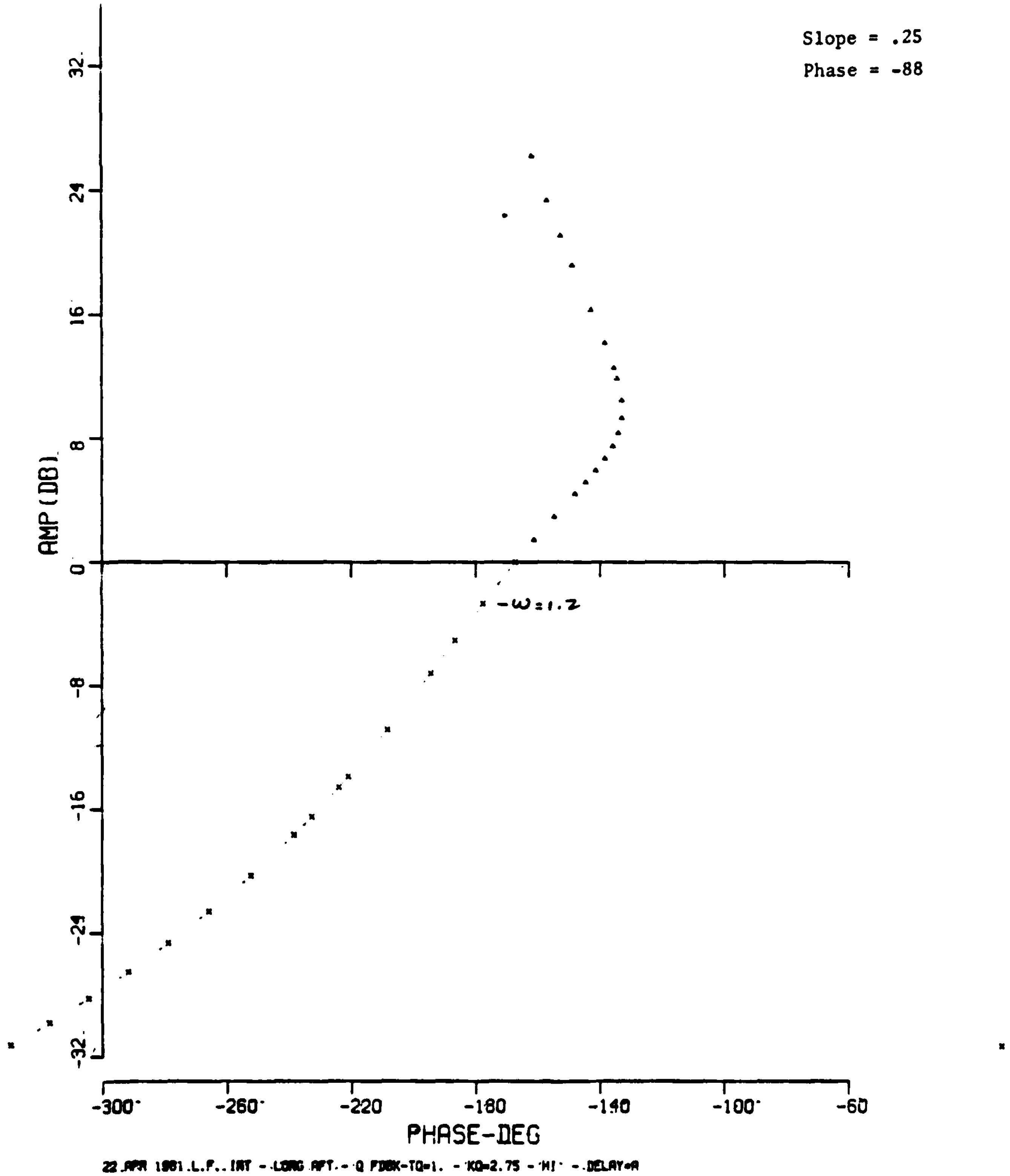

Slope = .30
Phase = -118
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
-ω=1.2
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
22 APR 1981 L.F. INT - LONG AFT - Q FDBK-TQ=1. - KQ=1.30 - MED. - DELAY=A



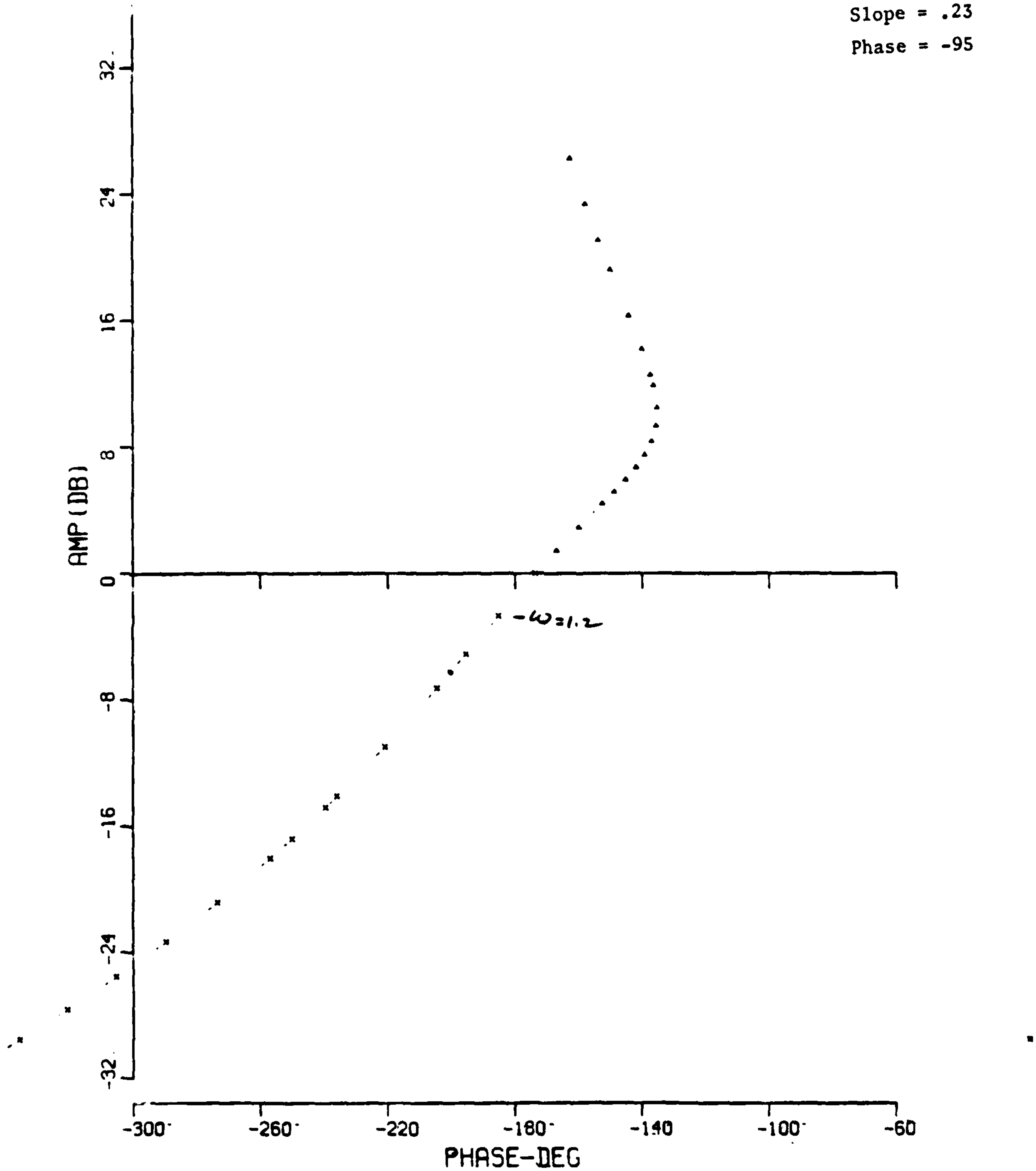
22.APR 1981.L.F. INT - LONG AFT - Q FDBK-TQ=1. - KQ=1.30 - MED - DELAY=8



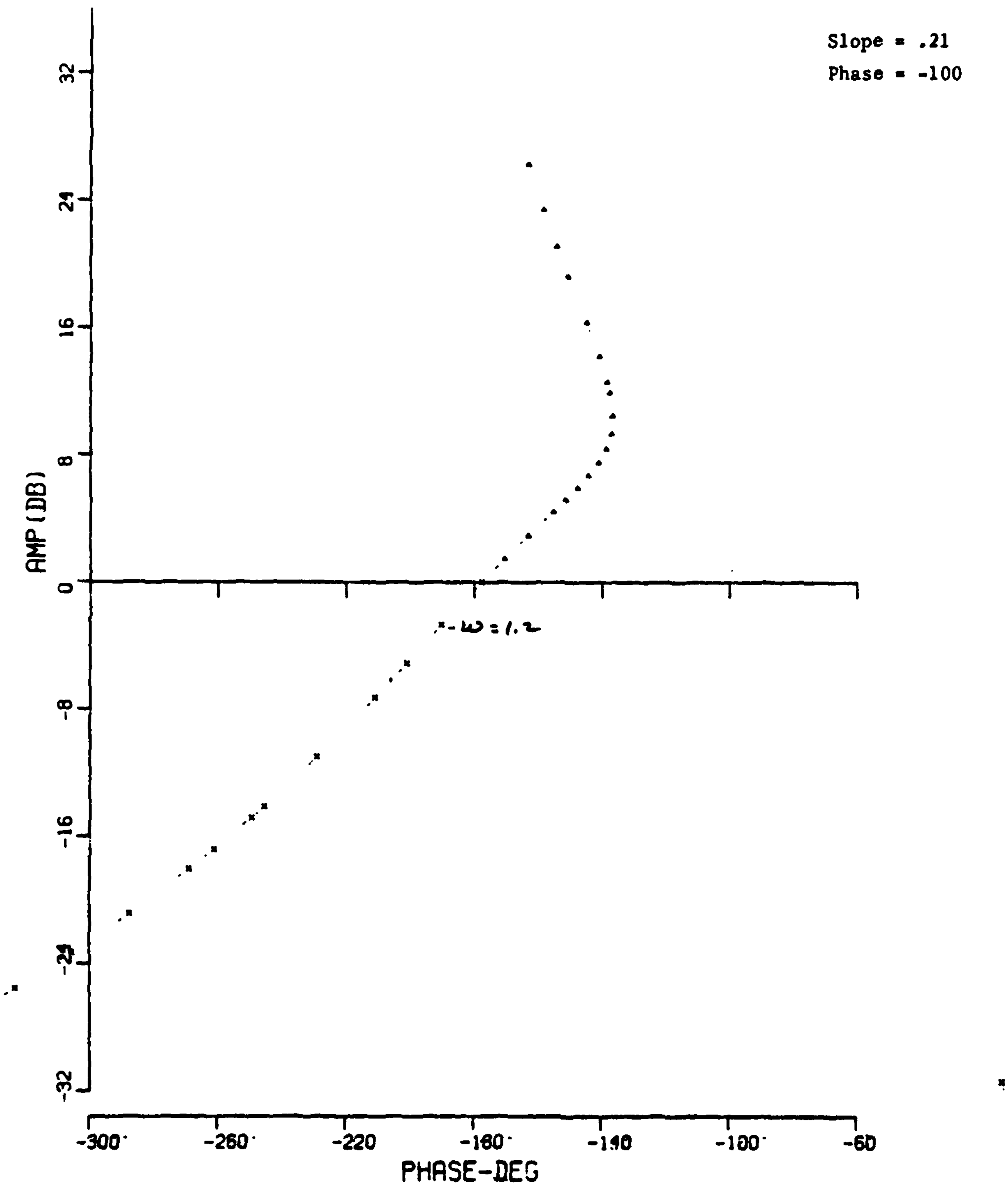
Slope = .26
Phase = -131
32.
24
16
8
0
-8
-16
-24
-32.
AMP (DB)
-ω = 1.2
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
22 APR 1981 L.F. IRT - LONG APT - Q FDBK-TQ=1. - KQ=1.30 - MED - DELAY=C



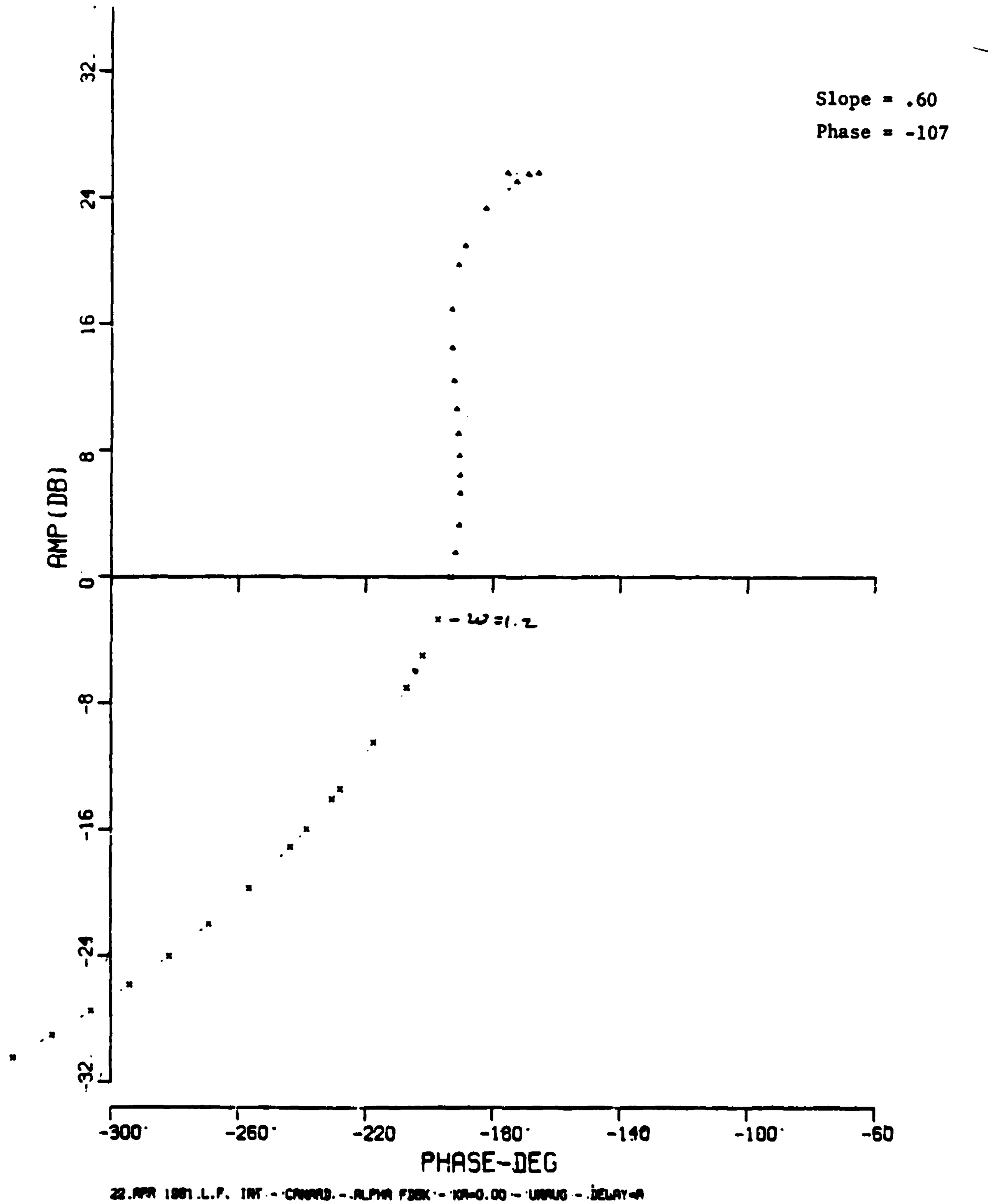
Slope = .25
Phase = -88
32
24
16
8
0
-8
-16
-24
-32
AMP (DB)
ω = 1.2
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
22 APR 1981 .L.F.. INT - LONG APT. - Q FDBK-TQ=1. - KQ=2.75 - HI - .DELAY=A

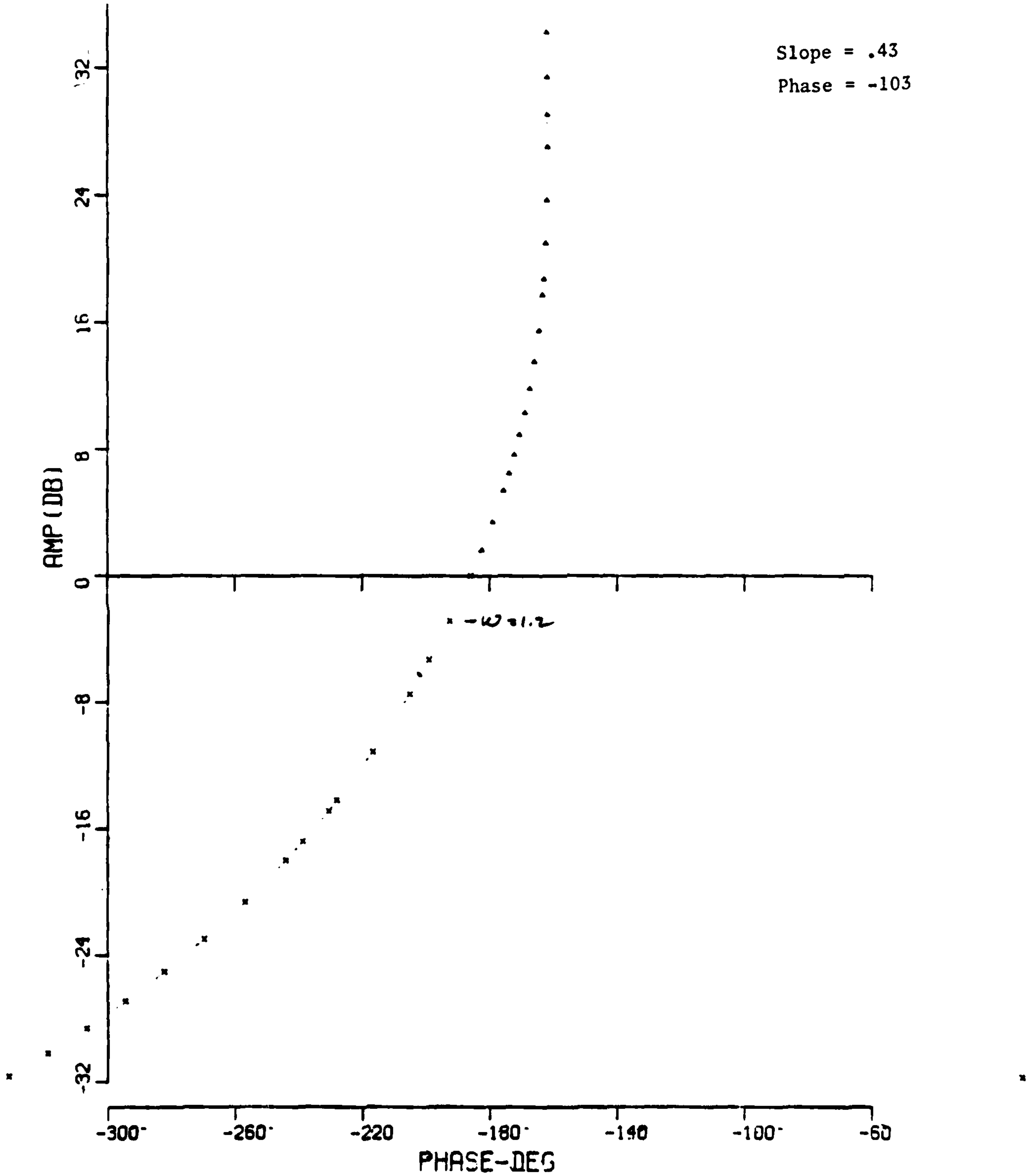


22.APR 1981 L.F. INT.--LONG AFT.- Q FDBK-TQ=1. - KQ=2.75 - HI - DELAY=8

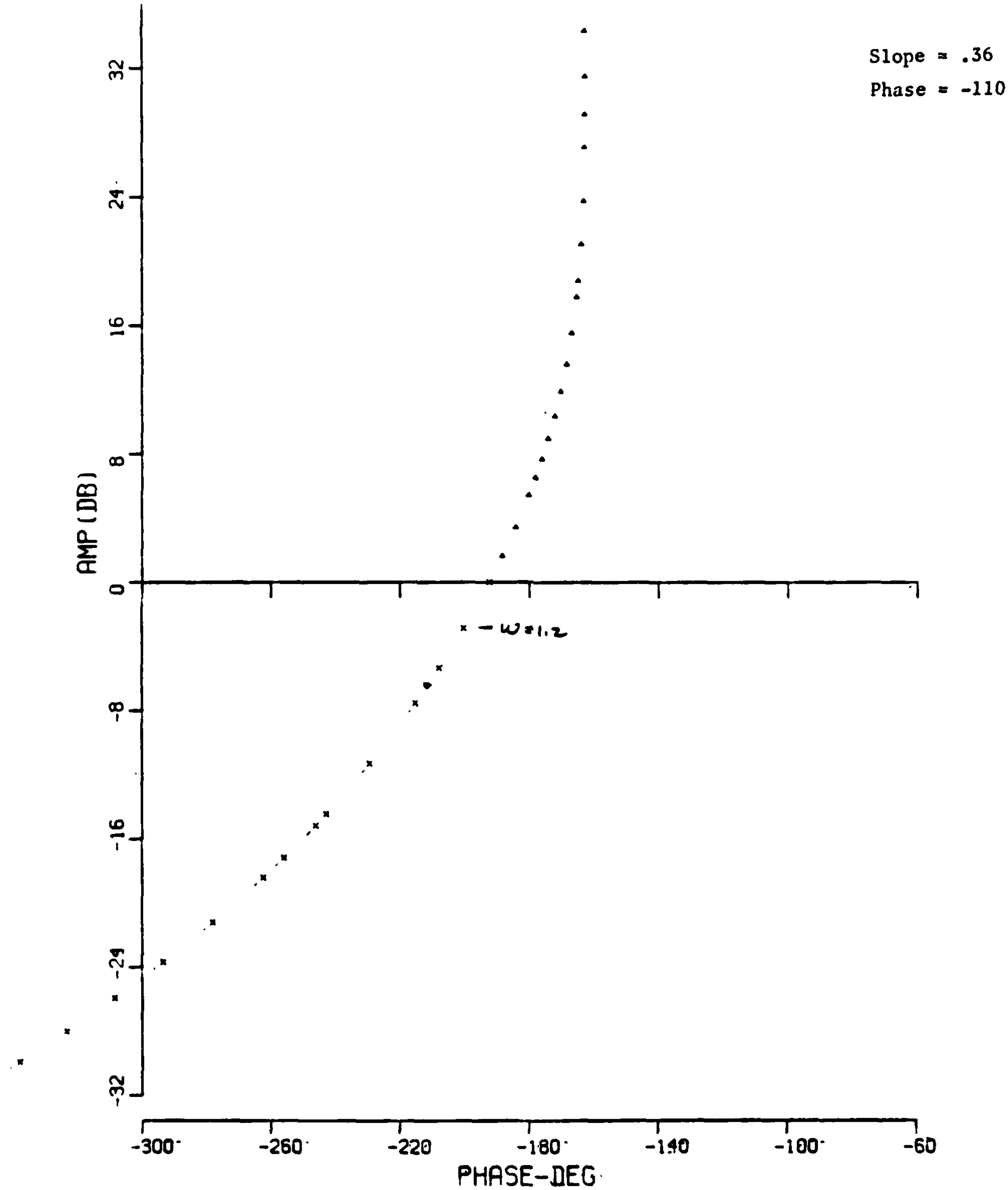


22 APR 1981.L.F.. INT.- LONG AFT - -Q FDBK-TB=1. - KQ=2.75 - HI - .DELAY=C

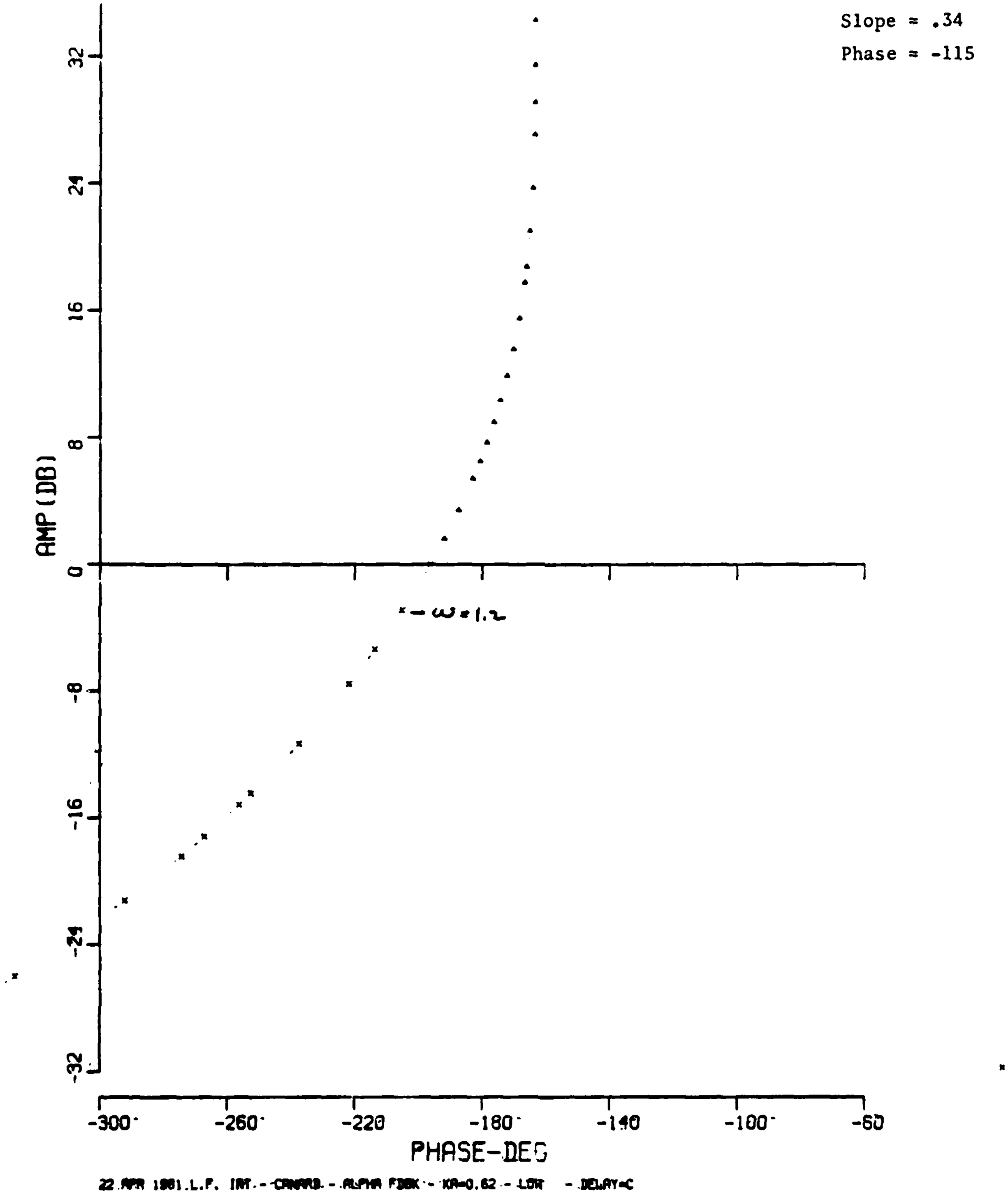

Slope = .60
Phase = -107
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
× - ω=1.2
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG

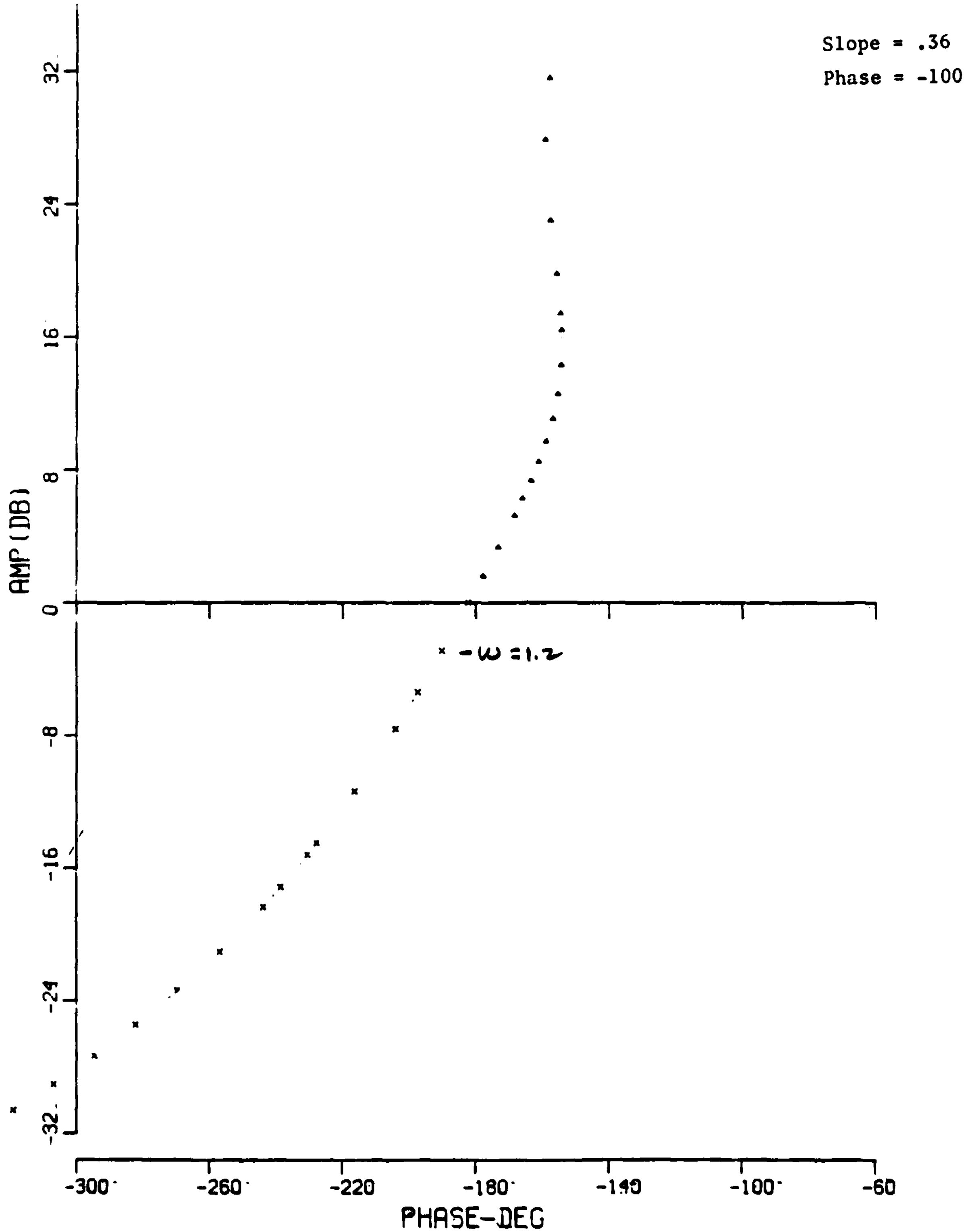


22 APR 1981 L.F. INT - CANARD - ALPHA FDBK - KA=0.52 - LOW - DELAY=A

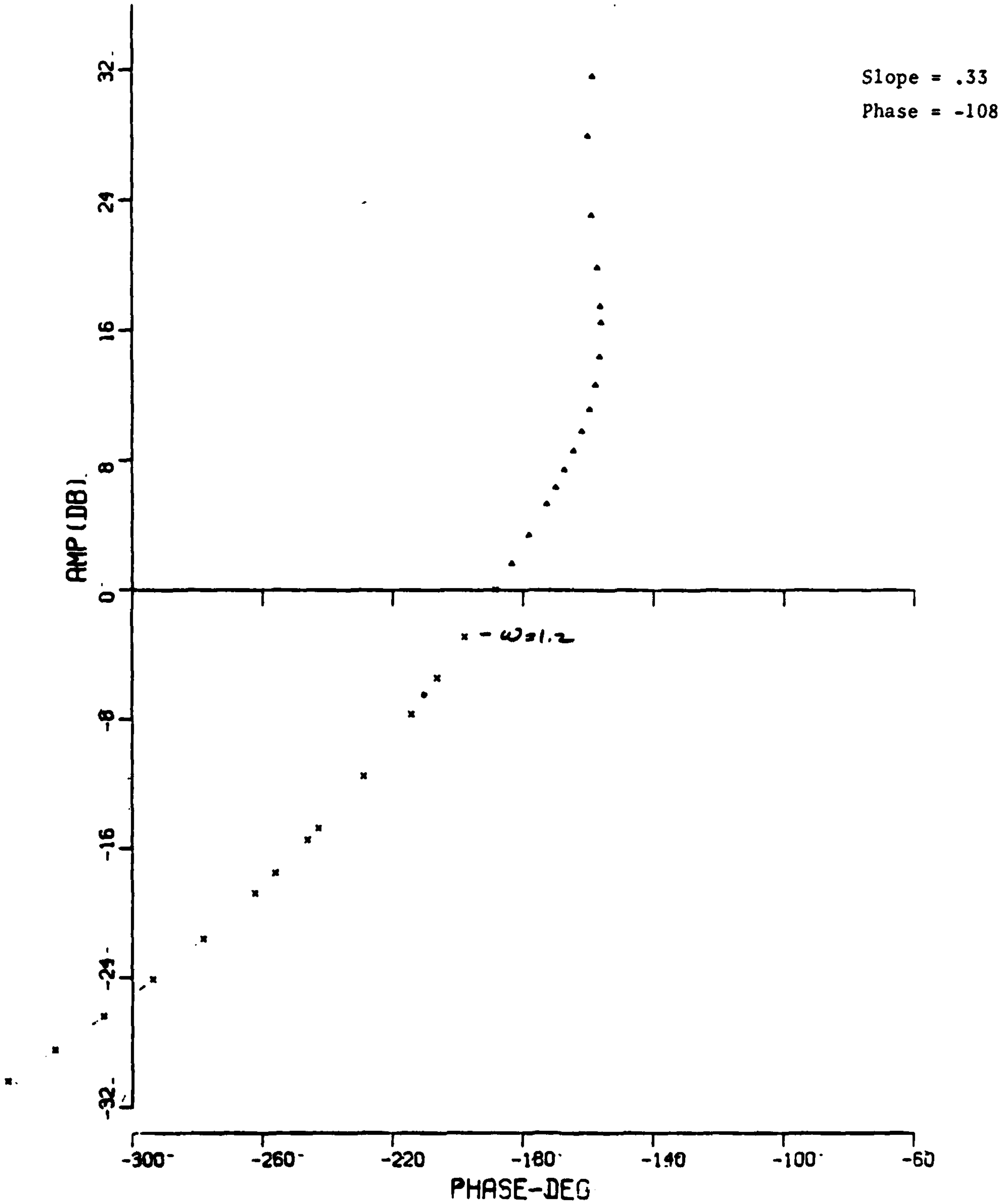


22 APR 1981 L.F. IRT - CANARD - ALPHA FDBK - KA=0.62 - LOW - DELAY=0

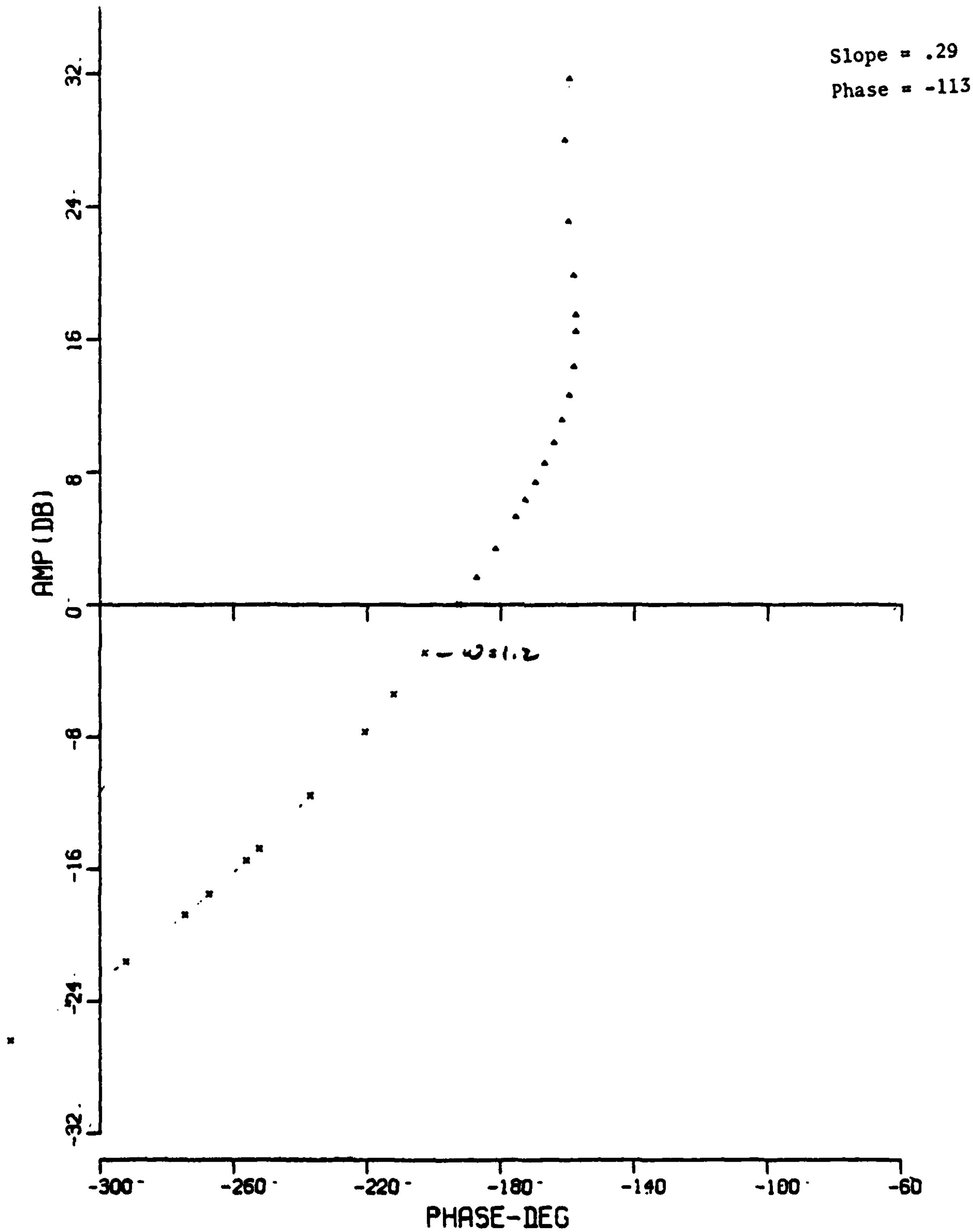

Slope = .34
Phase = -115
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
x — ω = 1.2
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
22 APR 1981.L.F. IRT - CANARD - ALPHA FDBK - KA=0.62 - LOW - DELAY=C



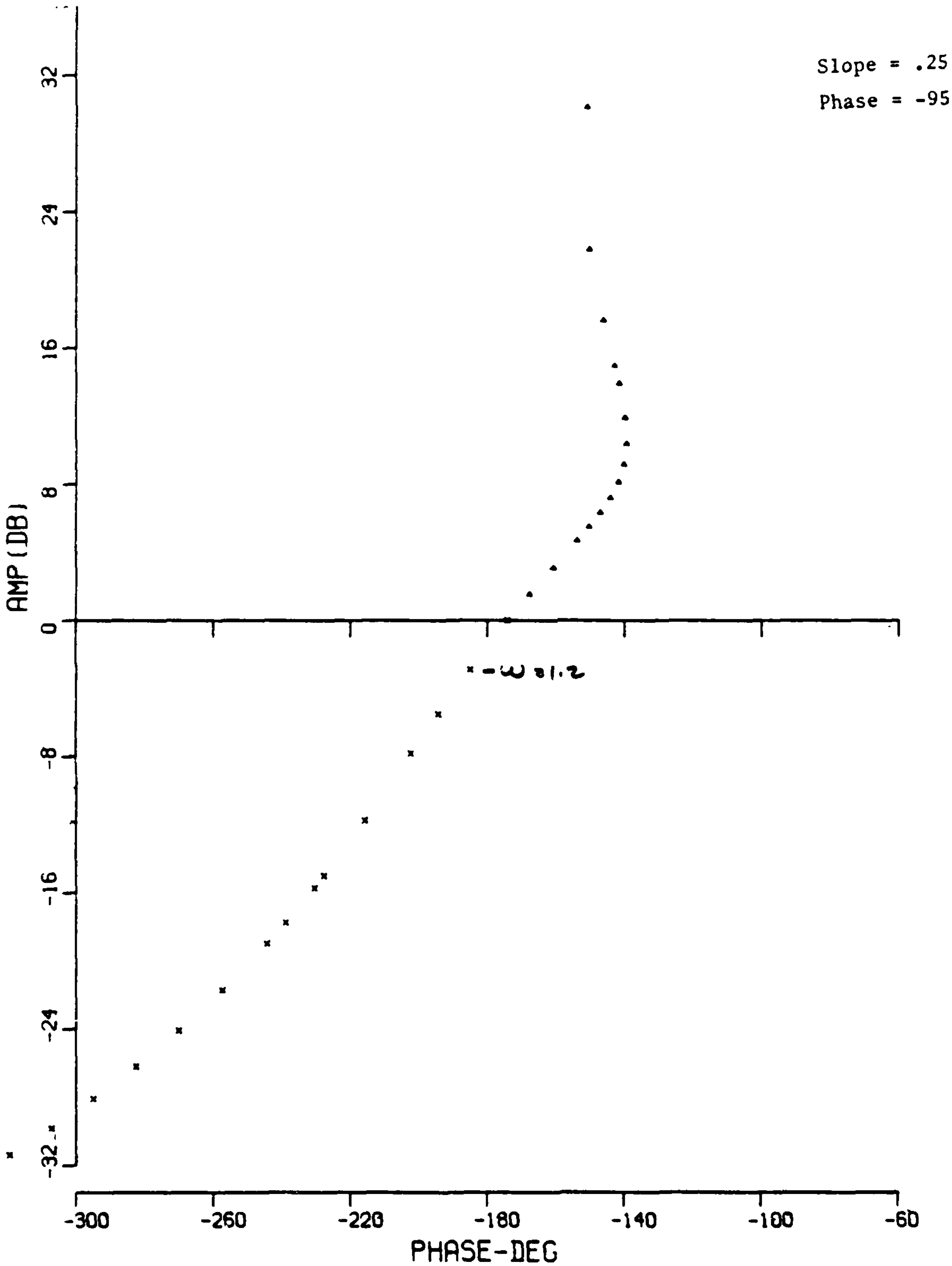
22.APR 1981 L.F. INT.-.CANARD-.ALPHA FDBK - KA=0.28 - MED. -.DELAY=A



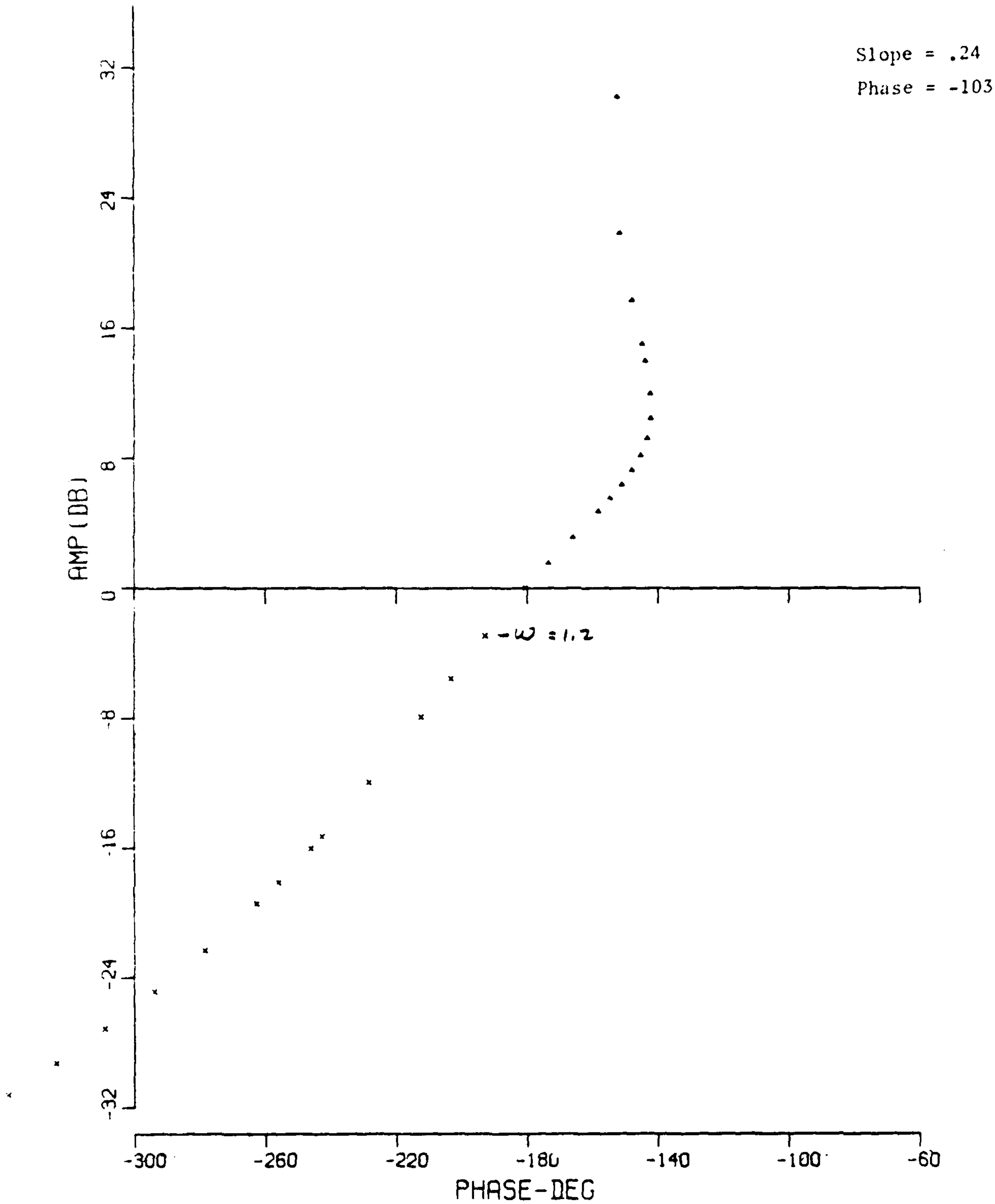
22 APR 1981 L.F. INT - CANARD - ALPHA FDBK - KA=0.88 - MED. - DELAY=8



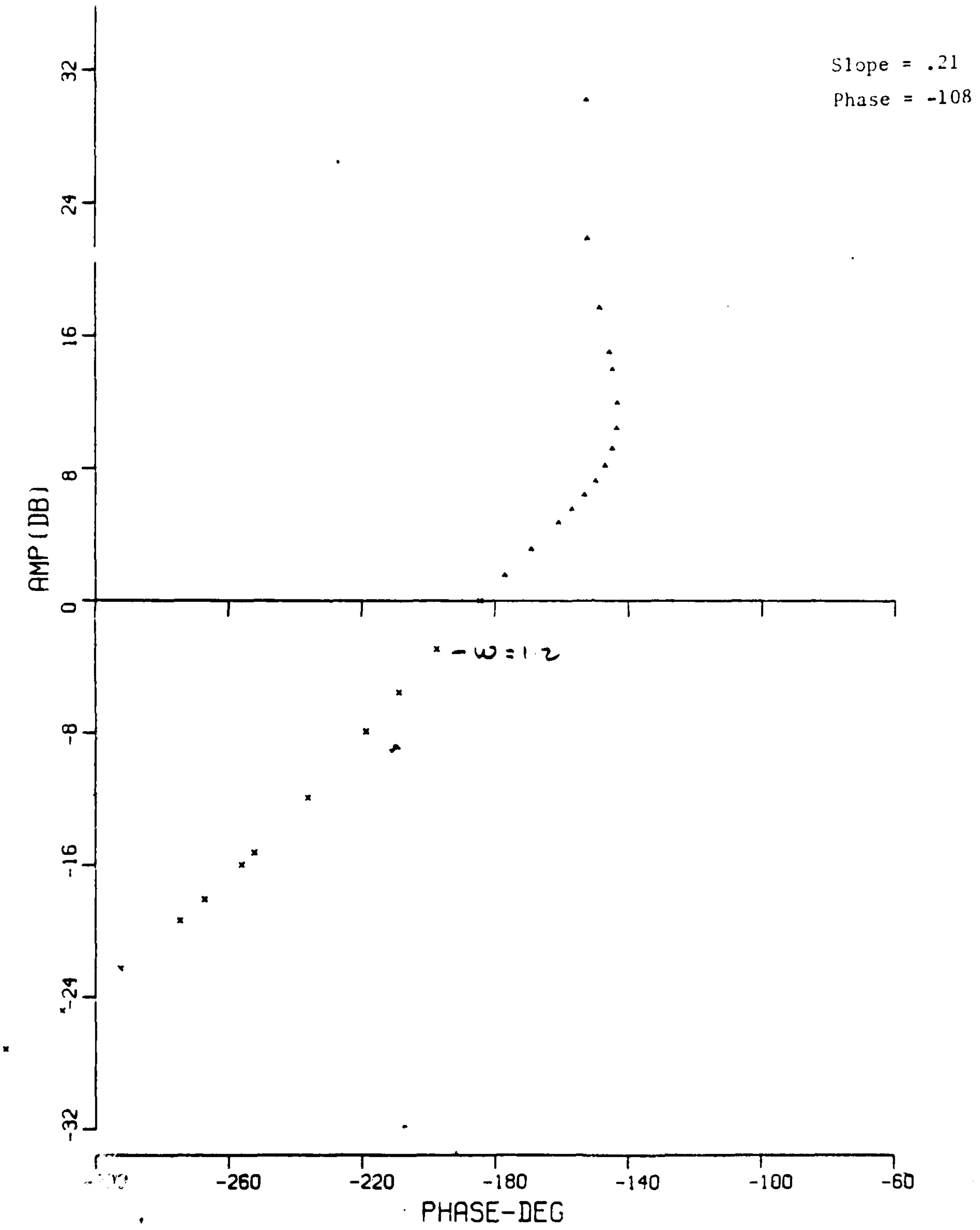
22 APR 1981 L.F. INT - CANARD - ALPHA FDBK - KA=0.88 - MED - DELAY=C



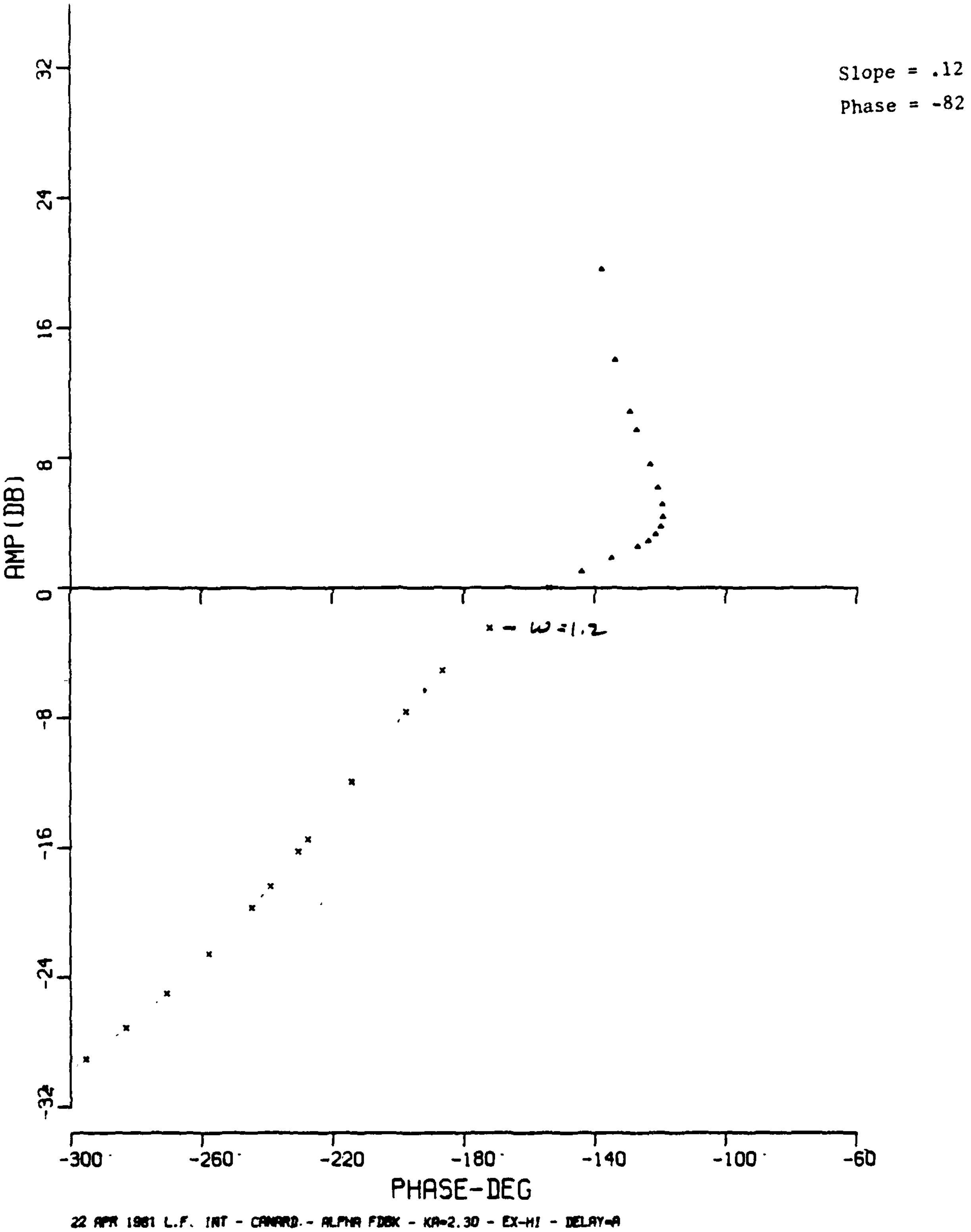
22 APR 1981 L.F. INT - CANARD - ALPHA FDBK - KA=1.36 - HI - DELAY=A



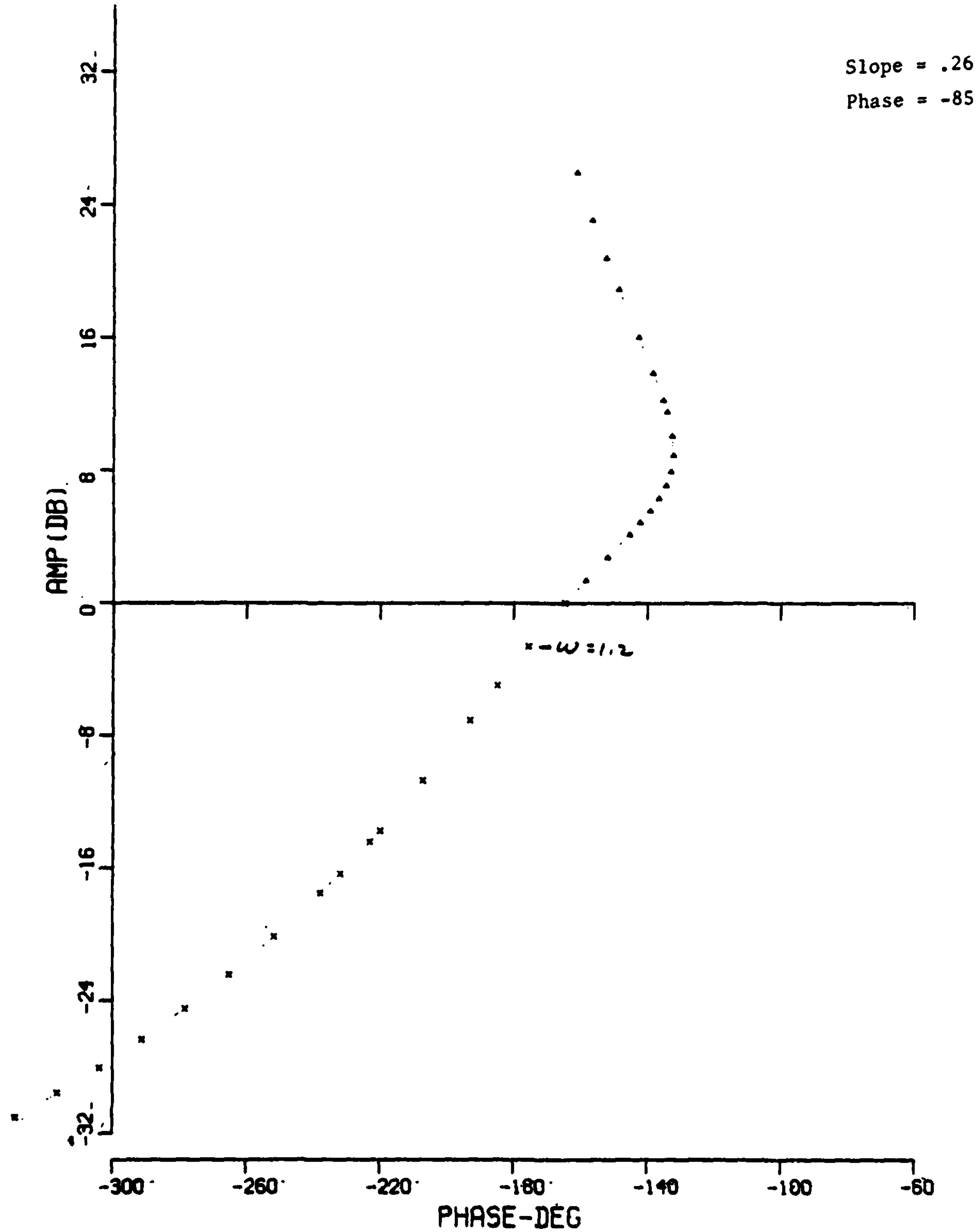
22 APR 1981 L.F. INT - CANARD - ALPHA FDBK - KA=1.36 - HI - DELAY=8

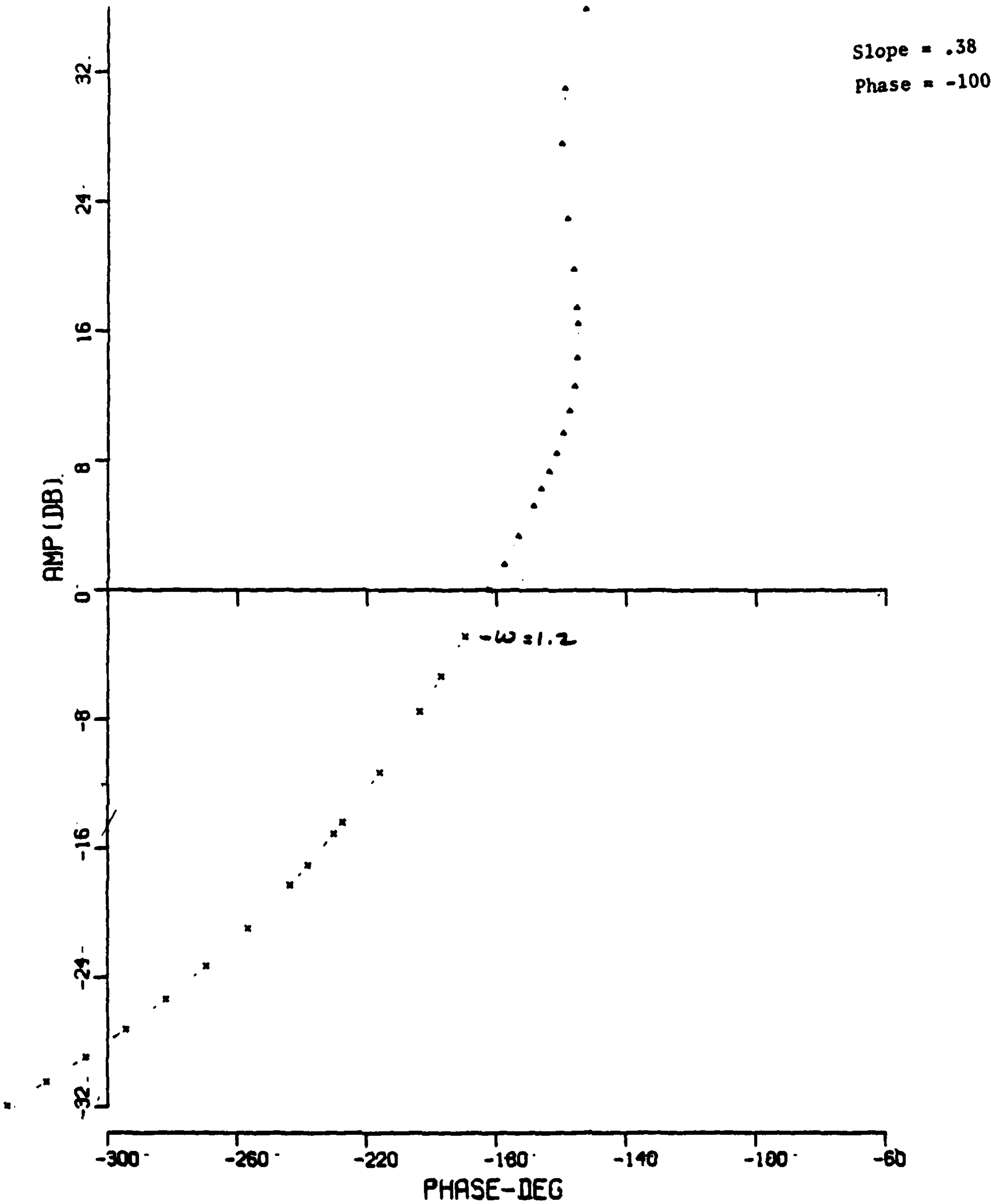


22 APR 1981 L.F. INT.- CANARD - ALPHA FDBK - KA=1.36 - HI - DELAY=C

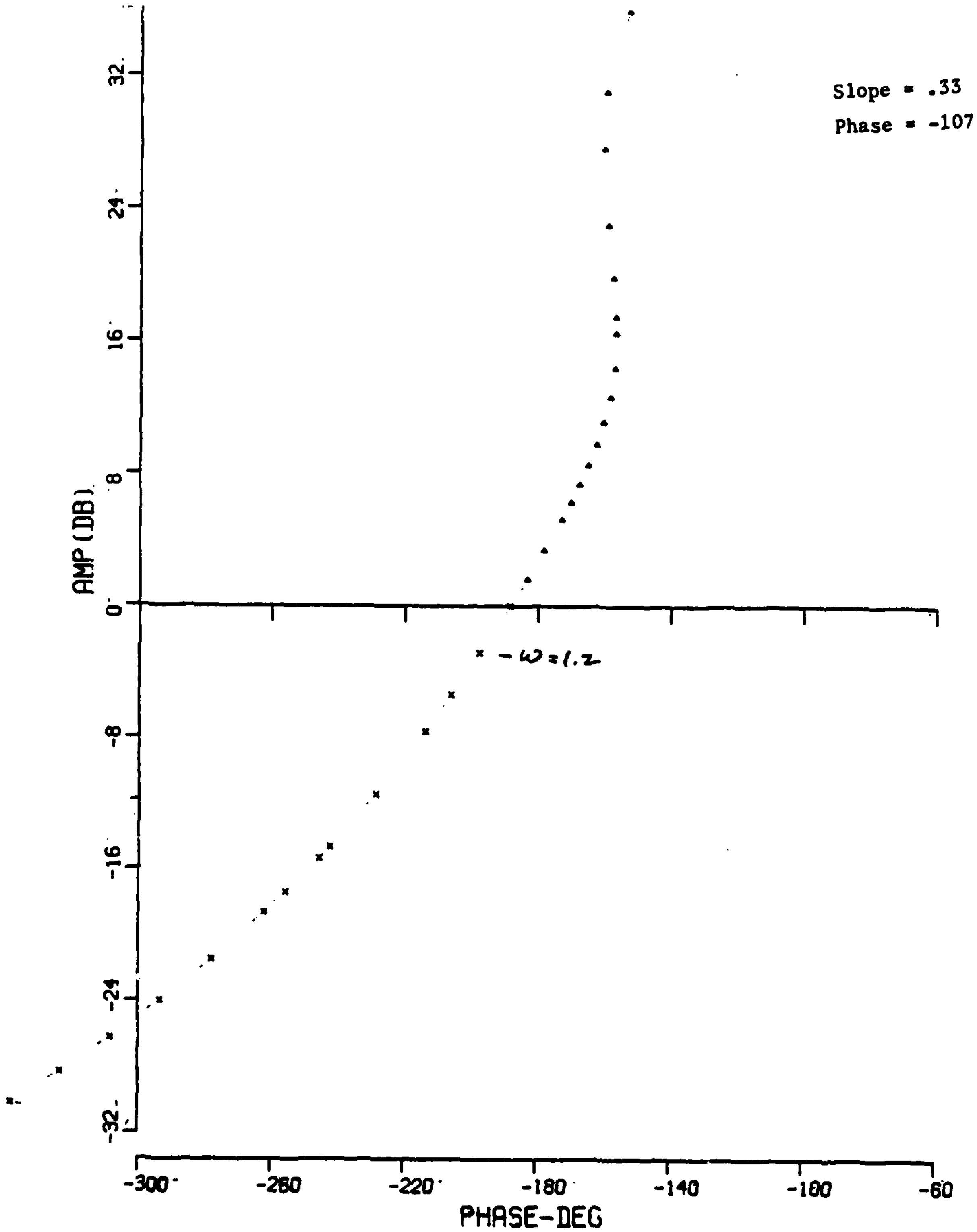


Slope = .12
Phase = -82
x - ω=1.2
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG
22 APR 1981 L.F. INT - CANARD - ALPHA FDBK - KA=2.30 - EX-HI - DELAY=A

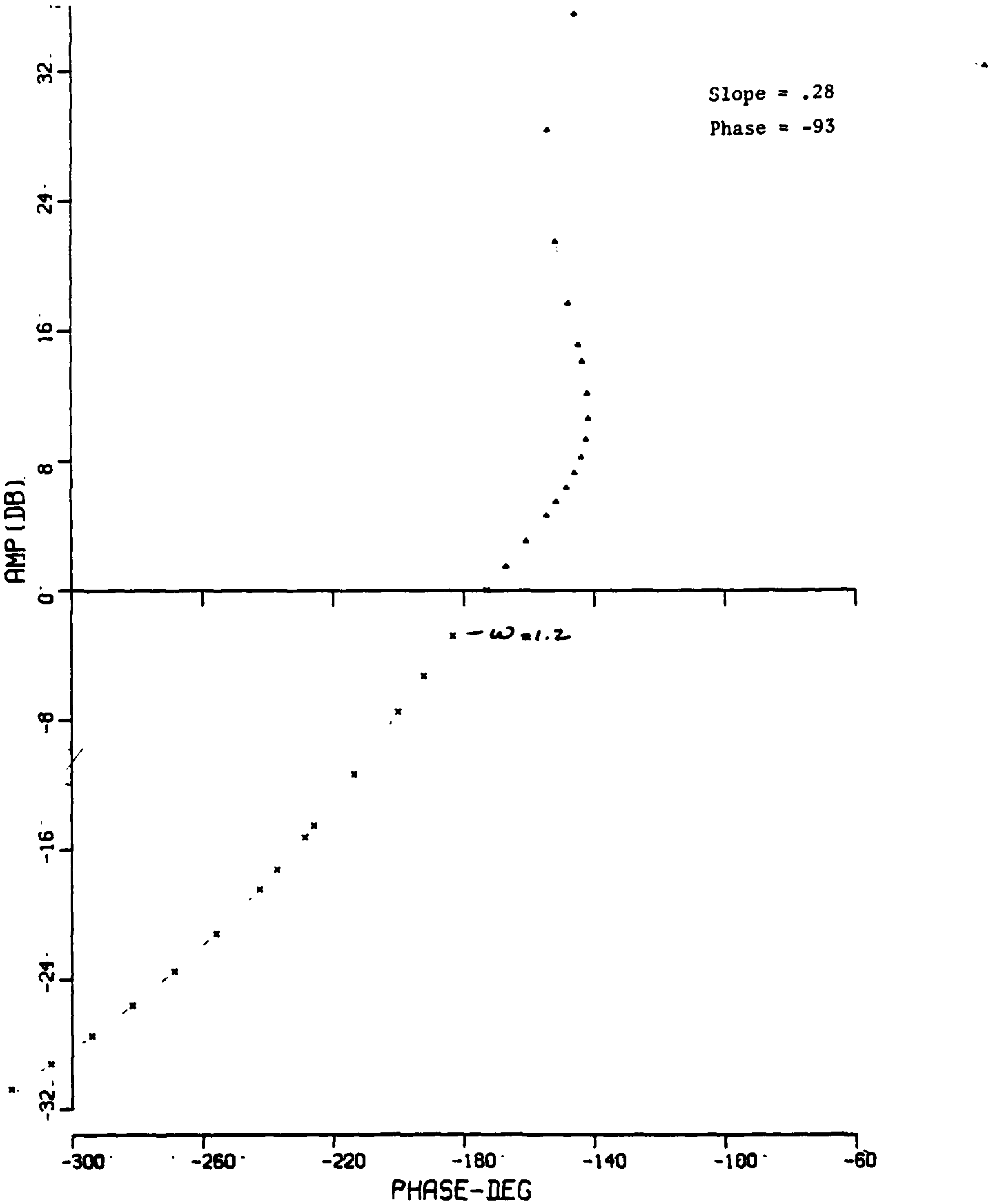

Slope = .26
Phase = -85
AMP (DB)
32
24
16
8
0
-8
-16
-24
-32
x – ω = 1.2
-300
-260
-220
-180
-140
-100
-60
PHASE-DEG



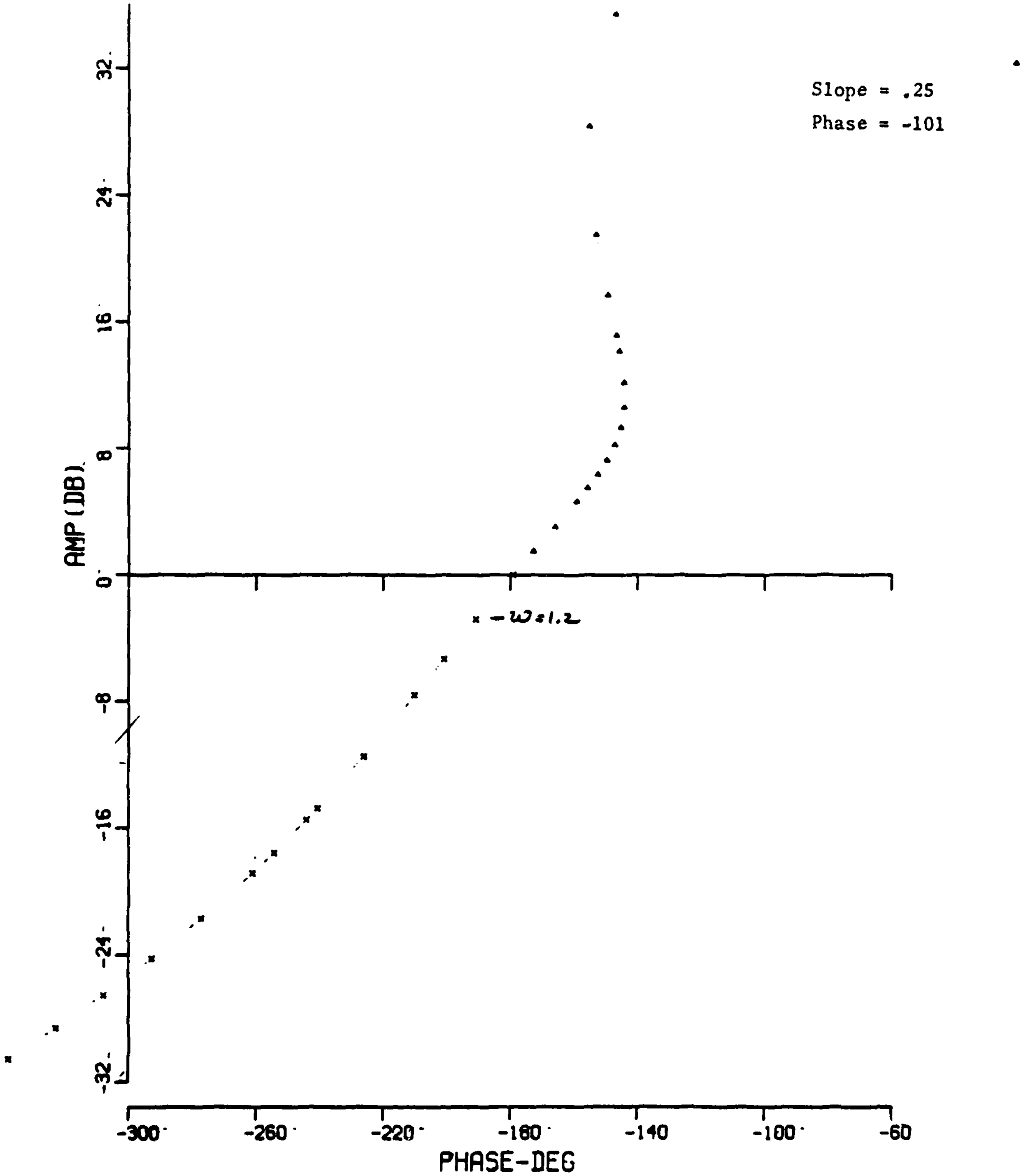
22 APR 1981 L.F. IRT - SHORT AFT - ALPHA FDBK - KA=0.85 - MED - DELAY=A



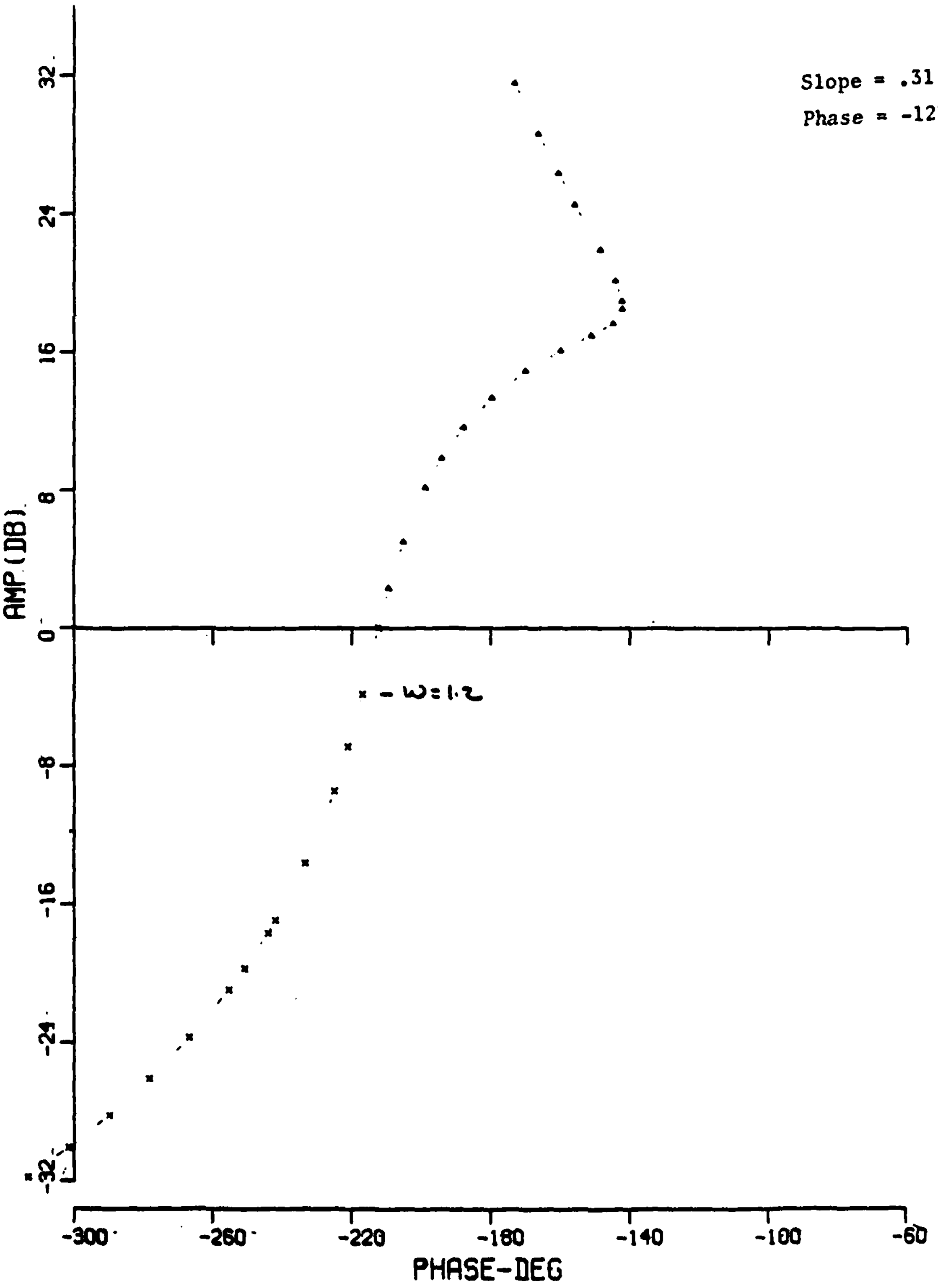
22 APR 1981 L.F. INT - SHORT APT - ALPHA FDBK - KA=0.65 - MED. - DELAY=8



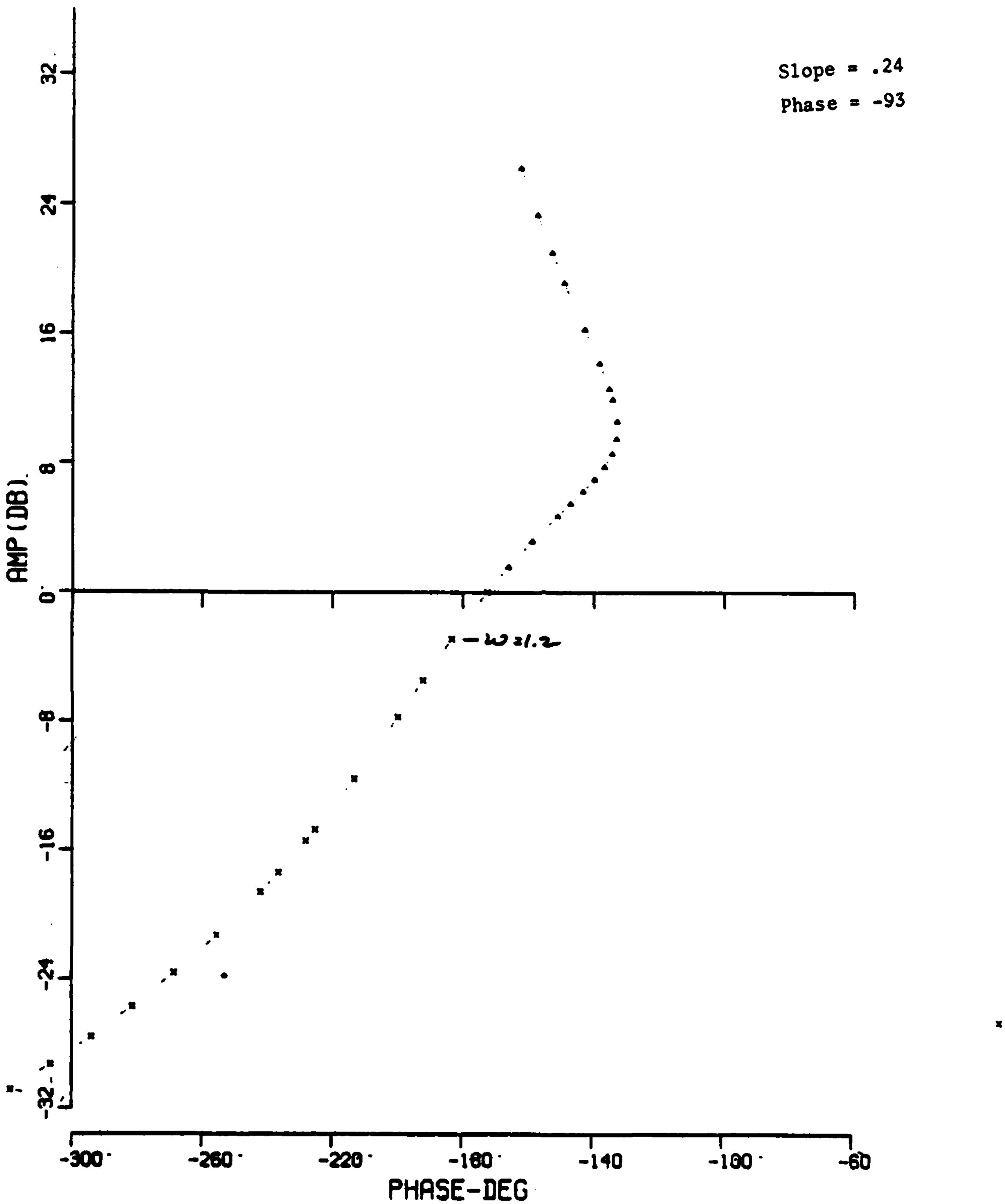
22 APR 1981 L.F. INT - SHORT AFT - ALPHA FDBK - KA=1.25 - HI - DELAY=A



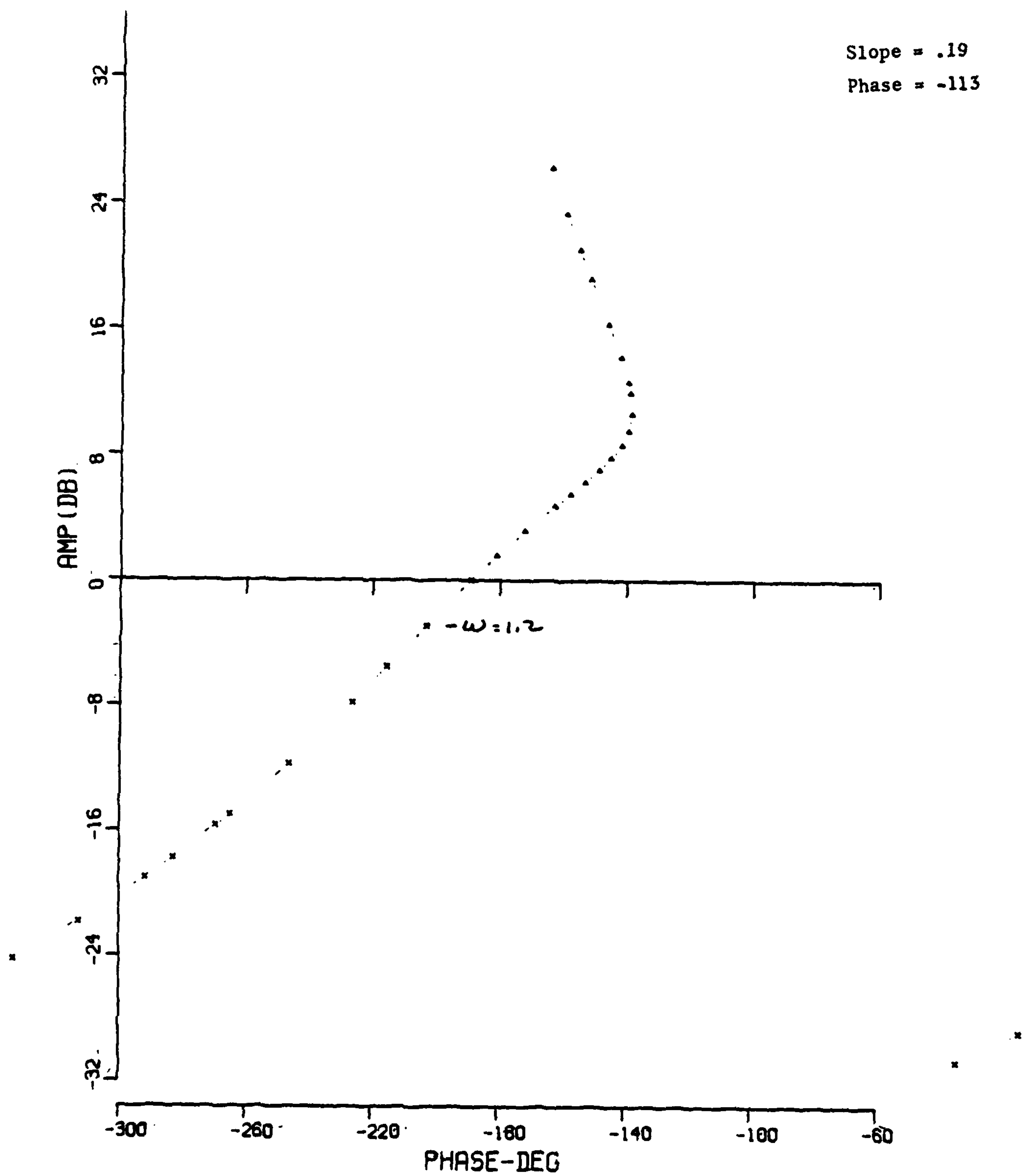
22 APR 1981 L.F. INT - SHORT AFT - ALPHA FDBK - KA=1.25 - HI - DELAY=8



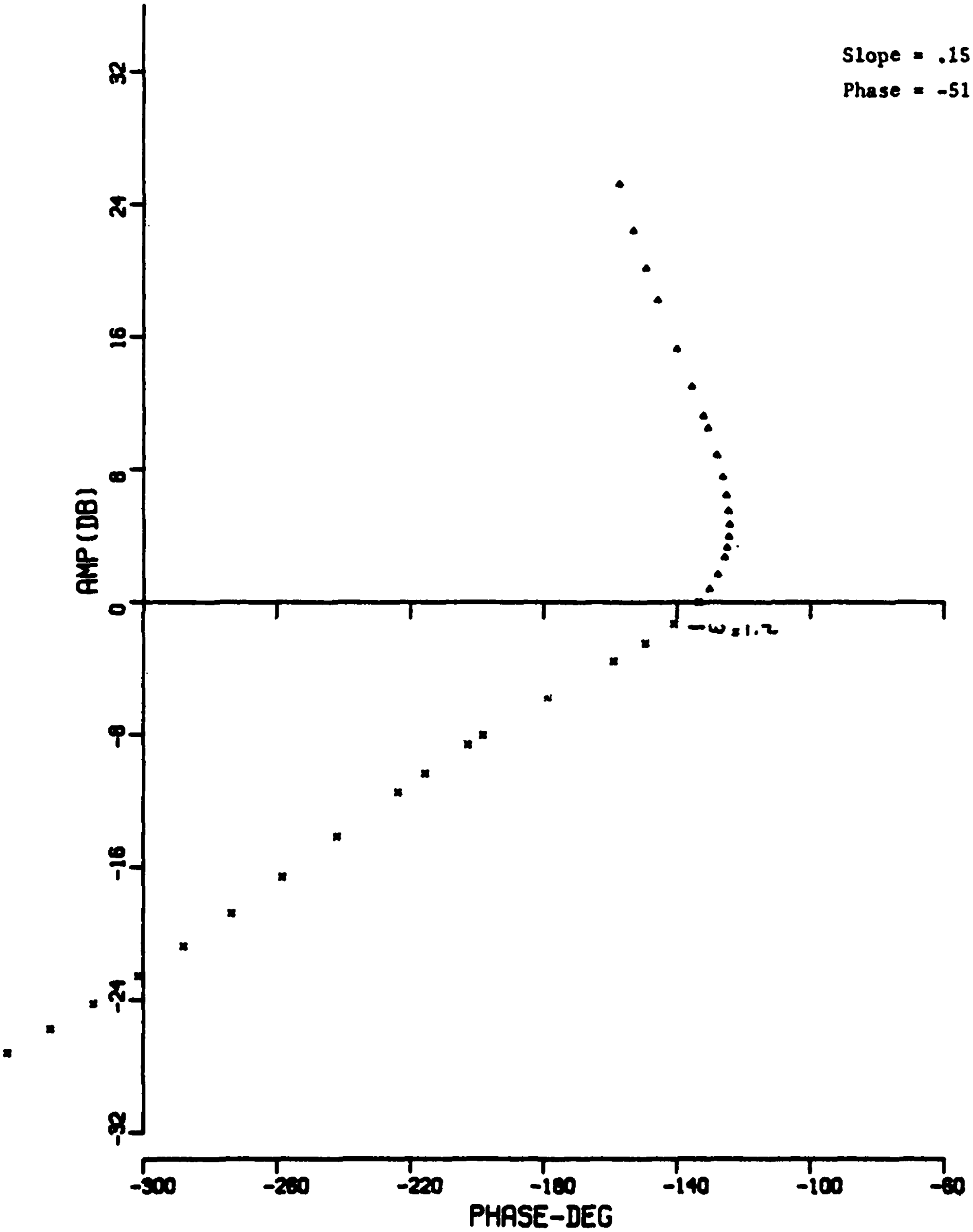
22 APR 1981 L.F. INT - SHORT RPT - Q FDBK-TQ=1. - KQ=1.05- - MED.- DELAY=A



22 APR 1981 L.F. INT.- SHORT.AFT.- Q FBBK-TQ=1. - KQ=2.50 - HI - .DELAY=Ø



22 APR 1981 L.F. INT - SHORT AFT - Q FDBK-TQ=1. - KQ=2.50 - HI - DELAY= .35



27 APR 1981 L.F. [illegible] - [illegible] APT - [illegible] - [illegible] - [illegible] - [illegible]=A

Appendix VI

MODEL FOLLOWING GAINS

This appendix contains a list of the TIFS control system gains which were used on the Large Airplane program. The constant gains used were optimized for the nominal indicated airspeed of 150 knots and a dynamic pressure of 76 pounds/ft^2.

Listed are the error feedback gains, model response feedforward gains, and crosswind compensation gains.

Error Feedback Gains

NOTE:
- Error signal (ϵx) = model value - TIFS value
- Angular units are degrees
- Velocity units are ft/sec

ELEVATOR:

$$\delta_e/\epsilon q = -2.0$$
$$\delta_e/\epsilon\Delta\theta = -5.0$$
$$\delta_e/\int \epsilon\Delta\theta = -2.5$$

DIRECT LIFT FLAP:

$$\delta_z/\epsilon\dot{\alpha} = -1.0$$
$$\delta_z/\epsilon\Delta\alpha = -8.0$$

THROTTLE:

$$\delta_x/\epsilon\dot{V} = 5.0$$
$$\delta_x/\epsilon\Delta V = 6.0$$

AILERON:

$$\delta_a/\epsilon p = -2.4$$
$$\delta_a/\epsilon\phi = -3.52$$

RUDDER:

$\delta_r/\varepsilon r = -1.94$

$\delta_r/\varepsilon\beta = 5.0$

$\delta_r/\int\varepsilon\beta = 3.132$

SIDE FORCE SURFACE:

No error feedbacks.

<u>Model Response Feedforward Gains</u>

NOTE:
- Angular units are degrees
- Velocity units are ft/sec
- n_y, n_z units are g's

ELEVATOR:

$\delta_e/\dot{q} = -.56$

$\delta_e/q = -.833$

$\delta_e/\dot{\alpha} = .223$

$\delta_e/\Delta\alpha = .0675$

$\delta_e/\Delta V = .028$

$\delta_e/\ddot{q} = -.0374$

$\delta_e/\ddot{\alpha} = .0163$

DIRECT LIFT FLAPS:

$\delta_z/\Delta n_z = -43.04$

$\delta_z/\Delta\alpha = -5.92$

$\delta_z/\Delta V = -.395$

$\delta_z/\dot{q} = .237$

THROTTLE:

$\delta_x/\dot{V} = 5.14$

$\delta_x/\Delta\alpha = -2.31$

$\delta_x/\Delta\theta = 2.87$

$\delta_x/\dot{\alpha} = -3.2$

$\delta_x/q = 3.86$
$\delta_x/\Delta V = .0375$
$\delta_x/\ddot{\alpha} = -.71$
$\delta_x/\dot{q} = .75$

AILERON:

$\delta_a/\dot{p} = -.595$
$\delta_a/p = -1.53$
$\delta_a/\dot{r} = -.312$
$\delta_a/r = .508$
$\delta_a/\dot{\beta} = -.172$
$\delta_a/\beta = -1.066$

RUDDER:

$\delta_r/\dot{r} = -1.16$
$\delta_r/r = 1.07$
$\delta_r/\dot{\beta} = 1.35$
$\delta_r/\beta = 1.09$
$\delta_r/p = -.376$
$\delta_r/\phi = -.195$

SIDE FORCE SURFACE:

$\delta_y/n_y = 124.$
$\delta_y/\beta = 2.3$
$\delta_y/\dot{r} = .68$

<u>Crosswind Compensation Gains</u>

NOTE:
- These gains multiply the β_{CW} (sideslip mismatch due to the artificial crosswind) and insert it into the feed-forward signals on the appropriate command amplifier.

- Units are deg/deg.

$\delta_a/\beta_{CW} = -1.07$
$\delta_y/\beta_{CW} = 2.29$

Appendix VII

RECORDING LIST

Digital Channel No.	Variable (all incremental values referenced to engage value)		Recording Scale Factor, units/volt
1	$\Delta\theta_m$	- incremental pitch attitude, model	2.5 deg
2	$\Delta\theta$	- incremental pitch attitude, TIFS	2.5 deg
3	q_m	- pitch rate, model	2. deg/sec
4	q	- pitch rate, TIFS	2. deg/sec
5	$\Delta\alpha_{IMTCG}$	- incremental angle of attack, inertial, model transformed to TIFS c.g.	2. deg
6	$\Delta\alpha_I$	- incremental angle of attack, inertial, TIFS	2. deg
7	ΔV_m	- incremental velocity, model	33.3 ft/sec
8	ΔV	- incremental velocity, TIFS	33.3 ft/sec
9	$\dot{V}_{MTCG}$	- longitudinal acceleration, model transformed to TIFS c.g.	2. ft/sec^2
10	$\dot{V}$	- longitudinal acceleration, TIFS	2. ft/sec^2
11	$\Delta N_{z_{PM}}$	- normal acceleration, pilot model	.25 g
12	ΔN_{z_p}	- normal acceleration, pilot TIFS	.25 g
13	$\dot{h}_{MTCG}$	- rate of climb, model transformed to TIFS c.g.	25 ft/sec
14	$\dot{h}$	- rate of climb, TIFS	25 ft/sec
15	F_{ES}	- pitch stick force	10 lb
16	F_{AW}	- roll wheel force	10 lb
17	$\dot{\alpha}_{IMTCG}$	- angle of attack rate, inertial, model transformed to TIFS c.g.	2. deg/sec
18	$\dot{\alpha}_I$	- angle of attack rate, inertial, TIFS	2. deg/sec
19	$\ddot{h}$	- altitude acceleration, TIFS	10 ft/sec^2
20	$\Delta N_{z_{CG}}$	- normal acceleration, c.g. TIFS	.25 g
21	ϕ_m	- bank attitude, model	10 deg
22	ϕ	- bank attitude, TIFS	10 deg
23	p_m	- roll rate, model	5. deg/sec
24	p	- roll rate, TIFS	5. deg/sec
25	r_m	- yaw rate, model	2. deg/sec

Appendix VII (CONT'D)

RECORDING LIST

Digital Channel No.	Variable (all incremental values referenced to engage value)		Recording Scale Factor, units/volt
26	r	- yaw rate, TIFS	2. deg/sec
27	β_{IMTCG}	- sideslip, inertial, model transformed to TIFS c.g.	2. deg
28	β_I	- sideslip, inertial, TIFS	2. deg
29	$N_{y_{pm}}$	- lateral acceleration, pilot model	.1 g
30	N_{y_p}	- lateral acceleration, pilot TIFS	.1 g
31	α_g	- angle of attack, turbulence component, model	2. deg
32	*		
33	α_{TM}	- angle of attack, total, model c.g.	2. deg
34	β_{TM}	- sideslip, total, model c.g.	2. deg
35	V_{IM}	- velocity, inertial, model	66.7 ft/sec
36	$\Delta N_{z_{MCG}}$	- incremental normal acceleration, model c.g.	.25 g
37	$N_{y_{MCG}}$	- lateral acceleration, model c.g.	.1 g
38	*		
39	*		
40	*		
41	δ_{EC}	- elevator column deflection	1. in
42	δ_{AW}	- aileron wheel deflection	10. deg
43	δ_{RP}	- rudder pedal deflection	.5 in
44	δ_{e_m}	- elevator surface deflection, model	2.5 deg

NOTE: *Various signals recorded to check TIFS sensor system; check flight folders for particular signal recorded.

Appendix VII (CONT'D)

RECORDING LIST

Digital Channel No.	Variable (all incremental values referenced to engage value)		Recording Scale Factor, units/volt
45	δ_{a_m}	- aileron surface deflection, model	10. deg
46	δ_{r_m}	- rudder surface deflection, model	5. deg
47	T	- thrust, model engines	[illegible]0,000 lb.
48	h_p	- pressure altitude, TIFS	2500 ft
49	h_{wh}	- wheel height, model	100 ft.
50	*G.S.D.*	- glide slope deviation (+ a/c high)	.05 deg
51	*Loc.Dev.*	- localizer deviation (+ a/c left of centerline)	.25 deg
52	*T.D.*	- touchdown pulse	---
53	$\delta_{e_{TIFS}}$	- elevator surface deflection, TIFS	2.5 deg
54	$\delta_{a_{TIFS}}$	- aileron surface deflection, TIFS	2. deg
55	$\delta_{r_{TIFS}}$	- rudder surface deflection, TIFS	10. deg
56	$\delta_{x_{Rt}}$	- throttle position, right, TIFS	10. deg
57	$\delta_{y_{Rt}}$	- side force surface deflection, right, TIFS	4. deg
58	$\delta_{z_{Rt}}$	- direct lift flap deflection, right, TIFS	4. deg

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